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HVM TAC was established in 1990, under funding from the Sustainable Environment Fund – Forest Renewal Initiatives Program, to establish a coordinated research and extension program supplying relevant information to hardwood and mixedwood forest managers. Representatives on HVM TAC include the Ministry of Forests (Forest Science Research Branch, Silviculture Branch, and Forest Regions), Ministry of Environment, Lands and Parks (Wildlife Branch), and Forestry Canada. Since its inception, a total of 40 projects have been supported province-wide.

The current hardwood research goal of HVM TAC is to support the acquisition, communication, and application of information needed for the sustainable and integrated management of hardwood and mixedwood resources.

The five year strategic plan for hardwood research outlines four priority areas for investigation. They are:

1. **Hardwood Silviculture,** to provide information on the effectiveness of silvicultural treatments;
2. **Ecology,** including site selection, stand dynamics, and site productivity studies to assist in operational decision-making;
3. **Integrated Resource Management,** to support the integration of hardwood harvesting and silviculture with other management objectives; and
4. **Forest Health,** including investigations into the nature, impacts, and control of organisms that damage hardwoods, and into the role of hardwoods in maintaining forest health.

Further information about the program can be obtained from Ministry of Forests, Forest Science Research Branch, 31 Bastion Square, Victoria, B.C. V8W 3E7.

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Ecology and Management of Paper Birch and Black Cottonwood in Southern British Columbia

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EXECUTIVE SUMMARY

Although there is an increasing interest and value in the commercial use of hardwoods in the southern interior of British Columbia, many problems are associated with their management and use. Our study was initiated to develop operations, research, and extension and demonstration priorities for hardwood and mixedwood timber management. The focus was on paper birch and black cottonwood in the Kamloops Forest Region.

The analysis examined hardwood inventory, ecology, management, and use issues through (1) a summary of hardwood inventory in the Kamloops Forest Region, (2) a field assessment of management practices and stand conditions in the productive ICHmw and IDFmw subzones in the region, and (3) a review of literature pertaining to paper birch and black cottonwood, which are the predominant species in the productive subzones.

The inventory summary indicates that there is a substantial hardwood volume in the Kamloops Forest Region, representing 1.8% (12.6 MM m^3) of the total wood volume (713.4 MM m^3). Trembling aspen makes up 60.3%, paper birch 36.4%, and black cottonwood 3.3% of that volume. Much of the aspen volume occurs in the drier, less productive ecological subzones. Unfortunately, many of the hardwood stands are over-mature because of lack of use. For example, 41% of the stands in the Kamloops TSA are older than 80 years, which is beyond the pathological rotation of paper birch and black cottonwood.

In the field assessment of productive subzones, regeneration (younger than 20 years) and immature-mature (older than 20 years) stands were sampled across a range of ecosystems (submesic to subhygric). For regeneration stands, the success of management practices for hardwood/conifer production was determined according to hardwood/conifer density and height growth. Hardwood production was most successful following light-impact broadcast burn and mechanical bunch-and-burn. Following those treatments, paper birch was the dominant hardwood and black cottonwood was generally restricted to skidroads. Conifer production was most successful following moderate-impact burns. Conifer success declined almost linearly from 80% following a 0 to 2-year planting delay to 0% following a 10-year delay.

Immature-mature stands were compared among ecosystems in terms of stand structure, species composition, and growth and yield. The hardwood and mixedwood stands sampled were generally even aged in all ecosystems. Uneven-aged distributions occurred, however, where canopy gaps developed as a result of root rot-caused mortality or selective cutting. The dominant species on submesic-mesic sites was paper birch (80% of the stand volume) and on subhygric-hygric sites, black cottonwood (70%). (Paper birch also occurred in minor amounts [20%] on subhygric sites.)

Growth (mean annual increment [MAI]) and yield (volume) of mature stands increased with moisture availability. The MAI (18.3 m^3/ha per year) and volume (1062 m^3/ha) reached their maximum on subhygric sites. The rotation age of hardwood stands in the ICH zone appears to occur between 50 and 60 years, based on the culmination of MAI and the onset of heart rot.

Operations, research and extension priorities were established after examining the inventory data, field practices and literature. We believe they are applicable throughout southern British Columbia. Three operational priorities were identified: (1) to update inventory; (2) to improve growth projections; and (3) to include hardwood and mixedwood management strategies in southern Interior TSA plans. These subjects are beginning to be addressed though regional data collection programs and regional decision-making at the TSA level.

Nine research priorities were identified under two major topics: (1) development of guidelines for silvicultural practices; and (2) evaluation of management effects on long-term ecosystem productivity.

The first requires the identification and classification of ecosystems suitable for hardwood and mixedwood management, the establishment of experimental plantations, the development of stocking standards, an evaluation of stand tending practices, an investigation of harvesting methods in mixedwood stands, and an evaluation of how pests and hardwood performance affect one another. The second topic, management effects

on long-term ecosystem productivity, needs to be evaluated in terms of stand dynamics, biomass production and nutrient capital, and species diversity. A well-directed hardwood and mixedwood research program should address these research priorities through process-oriented experiments, long-term experiments, trials, and surveys. The information gathered should then be used to make predictions concerning the function and productivity of our forests under current and predicted management conditions.

Extension and demonstration priorities to improve awareness of hardwood and mixedwood management and use include the establishment of demonstration areas over a range of stand and site conditions, and the support of an extension program through the development of workshops, handbooks, and training courses.

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INTRODUCTION

Hardwoods are considered the "Cinderella trees" of the 1990's in the southern interior of British Columbia. They have long been cut, burned, and sprayed to create coniferous forests of high quality. Recently, however, there have been concerns that this expensive eradication policy is a mistake. Not only is the demand for hardwoods growing, but concerns have developed over the negative aspects of growing coniferous monocultures. Indeed, hardwoods will likely play a crucial role, both ecologically and socially, in the health of our future forests.

In this analysis we explored the problems associated with the management and use of hardwood and mixedwood forests. The intent was to study aspects of the debate surrounding hardwood and mixedwood management, and to develop research priorities for the southern Interior. Our focus was the Interior Cedar Hemlock (ICH) and Interior Douglas-fir (IDF) zones, where hardwoods reach their greatest productivity and are the most easily accessible. The hardwood species we investigated were primarily paper birch (*Betula papyrifera*) and secondarily black cottonwood (*Populus balsamifera* ssp. *trichocarpa*). Problems related to trembling aspen (*P. tremuloides*) have already been reviewed by others (e.g., Peterson *et al.* 1989) in western Canada, and hence the species was not considered a high priority here. The study was restricted to timber management issues.

Use of existing stands forms the basis for today's hardwood and mixedwood management. Once current stands are harvested, regeneration and stand tending practices can be applied to produce high quality, stocked second-growth stands. The successful use of these managed stands will depend on the timing of harvest: the trees must be harvested after they are large enough to manufacture, but before decay is advanced. The development of successful hardwood and mixedwood management strategies will therefore require that managers have an understanding of (1) species composition, growth, yield and decay in existing stands, (2) autecology and management responses of the component species, and (3) effects of current management practices on second-growth stand quality.

We addressed these topics by reviewing the inventory in the Kamloops Forest Region, the literature pertaining to the autecology and management of paper birch and black cottonwood, and the field sites that represent the spectrum of current management practices and stand conditions in the productive ICH and IDF zones. Using the information gathered, we proposed guidelines for silviculture prescriptions and identified research priorities.

The field assessment was broken into two phases. First, regeneration stands (younger than 20 years) were sampled to identify management practices that were successful for hardwood, conifer or mixedwood production. Second, immature-mature stands (older than 20 years) were sampled across a range of ecosystems (submesic to subhygric) to assess their stand structure, species composition, and growth and yield. This dual phase approach allowed us to evaluate the effects of current management practices on second-growth stand structure and composition, and to identify reasonable growth and yield projections for managed stands.

The specific objectives of the analysis were:

1. to describe the extent (volume by age class) and distribution of hardwoods in the Kamloops Forest Region;
2. to describe hardwood communities dominated by paper birch and black cottonwood in terms of their ecosystem classification, species composition, community structure, stocking, site index, conifer success, and successional status;
3. to summarize silviculture treatments that have been applied to harvested sites in the productive ICHmw and IDFmw subzones, and to determine which treatments increase or decrease hardwood composition;
4. to recommend treatments for timber management of paper birch and black cottonwood communities for the stand composition objectives: pure hardwoods, pure conifers, and mixedwood;
5. to identify research priorities for hardwood timber management in the Kamloops Forest Region; and
6. to locate sites suitable for demonstration of hardwood timber management practices.

2 METHODS

2.1 Summary of Extent and Distribution of Hardwoods

The extent and distribution of paper birch, black cottonwood and trembling aspen were summarized from Ministry of Forests inventory reports for the Kamloops, Okanagan, Merritt and Lillooet Timber Supply Areas (TSA's). The latest inventory updates for the four TSA's were October 1989, August 1986, November 1988, and April 1989, respectively. The estimates were based on a close utilization level of 12.5 cm breast-height diameter and 10 cm top diameter, minus decay, waste and breakage. The inventory was broken down by maturity class, type group, and region and compartment.

2.2 Literature Review

Literature reviews of the autecology, management and use of paper birch and black cottonwood are presented in Appendices 1 and 2, respectively. The specific topics addressed were: distribution, habitat, reproduction, growth and development, growth and yield, succession, productivity in mixed stands, effects on ecosystem productivity, pests, wood quality, and wood uses. The responses of paper birch and black cottonwood to management practices (such as canopy removal, fire, cutting, herbicides, soil disturbance and fertilization) were not reviewed here, but are included in Haeussler *et al.* (1991).

2.3 Field Procedures

Field sampling was limited to the four biogeoclimatic units that are the most productive for birch and black cottonwood growth in the Kamloops Forest Region (D. Lloyd, 1989, pers. comm.). Those units are the Thompson Moist Warm ICH (ICHmw3) variant, the Shuswap Moist Warm ICH (ICHmw2) variant, the Thompson Moist Warm Interior Douglas-fir (IDFmw2) variant, and the Shuswap Moist Warm IDF (IDFmw1) variant.

Key drainages with substantial areas of hardwood and mixedwood stands were identified from personal experience and discussions with Ministry of Forests personnel. Forest cover and biogeoclimatic maps of the identified drainages were examined. Sample openings and polygons were chosen to represent ranges in: (1) deciduous and deciduous/coniferous timber types; (2) moisture regime (subxeric to hygric); (3) age (5–100 years); (4) geographical location; and (5) commonly practiced silviculture treatments. The field study was conducted in October 1989. Twenty-six of the 60 polygons/openings that were assessed were located in immature or mature stands older than 20 years; 34 were in immature stands younger than 20 years.

2.3.1 General Information

The general information recorded for each opening included: biogeoclimatic subzone, ecosystem association, hygrotope, terrain classification, soil texture, slope, slope position, aspect, silviculture system (year and method), site preparation (year, type and intensity), planting (year and species), and presence of root rot.

2.3.2 Site disturbance

The impact of silviculture treatments was qualitatively assessed for each site in terms of burn severity and mechanical disturbance. Burn severity was rated based on slash abundance, slash condition, duff depth, and mineral soil exposure.

2.3.3 Community description

We determined species composition and community structure by walking through each opening and gathering data in sample plots. The data collected depended on whether the stand was in a regeneration age class (younger than 20 years) or older (20–100 years old).

STANDS OLDER THAN 20 YEARS

Two fixed radius cruise plots were sampled in each opening/polygon according to procedures described by Walmsey *et al.* (1980). The information collected was used to determine stand density, volume and site index. Stands were rated as successful, moderately successful or not successful for hardwood, conifer and mixedwood production, according to species composition, growth and yield.

STANDS YOUNGER THAN 20 YEARS

Five 50-m^2 ($r = 3.99$ m) stocking plots were usually sampled in each opening according to procedures by the Ministry of Forests (1989). Minimum and target stocking standards were determined for each site using regional Stocking Standards (Lloyd *et al.* 1990).

The characteristics recorded for the dominant hardwood species in the community included total stems per hectare, and height, diameter and number of stems per clump for a sub-sample of individuals. The characteristics recorded for the dominant coniferous species included: number of total and well-spaced stems per hectare; number of free-growing stems per hectare; relative height (%) to hardwoods; and height and length of last year's leader for a subsample of individuals.

Regeneration success of hardwoods was determined based on density and species composition. Openings were classified in terms of hardwood regeneration success as: successful (stocked with acceptable species); moderately successful (nearly stocked with acceptable species); or unsuccessful (not stocked with acceptable species).

Regeneration success of conifers was determined based on the number of well-spaced stems per hectare, species composition, free-growing status, and height growth rates. Openings were classified in terms of conifer regeneration success as: successful (stocked with rapidly, free-growing acceptable species); moderately successful (stocked or nearly stocked with acceptable species that are suppressed by overtopping hardwoods); or unsuccessful (not stocked with acceptable species).

2.3.4 Site history

Site history was examined for each site to identify relationships between type of disturbance or management practices and current stand conditions. Factors considered included: species composition of harvested and adjacent stands; silviculture treatment regime; type and degree of site disturbance; environmental and site limitations; and pathogen or insect damage.

2.3.5 Demonstration sites

Sites suitable to demonstrate hardwood management techniques were identified according to the following criteria: closeness to district offices or a major population centre; suitability for hardwood or mixedwood management; and uniformity of site conditions.

2.3.6 Analytical approach

Cruise information collected from stands older than 20 years was used to determine site index, volume and stocking; regeneration information from stands younger than 20 years was used to assess early growth and stocking. Management practices that have been successful for hardwood, conifer or mixedwood production in the range of ecosystems sampled were identified.

STANDS OLDER THAN 20 YEARS

Stands were described in terms of species composition, density (stems per hectare and basal area), site index (50 years), volume, and mean annual increment; and compared by ecosystem unit, site history and age class.

Stands younger than 20 years

Conifer and hardwood regeneration was described in terms of height, density (total, well-spaced [conifers only] and free-growing [conifers only] stems per hectare), and relative height (%) of conifers to hardwoods. The success of silviculture treatment regimes was identified according to the proportion of openings that were adequately stocked with rapidly growing, acceptable species.

2.3.7 Limitations

The value of the information collected during the field study is limited by the small sample size. The intent was not to make statistically sound comparisons, but rather to identify trends among observations and provide an estimate of error.

3 INVENTORY

The total hardwood inventory on Crown land in the Kamloops Forest Region, measured to close utilization standards,[1] consists of 12.63 MM m^3. This accounts for 1.8% of the total wood volume in the region. Although the hardwood inventory appears to be trivial compared to the softwood inventory of 700.8 MM m^3, its volume is substantially undervalued.

The hardwood inventory in the Kamloops Region includes only three species: trembling aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), and black cottonwood (*Populus balsamifera* var. *trichocarpa*). It consists of 7.6 MM m^3 (60.3%) of trembling aspen, 4.6 MM m^3 (36.4%) of paper birch, and 0.4 MM m^3 (3.3%) of black cottonwood. Within the Kamloops Region, trembling aspen predominates in the south and west, and paper birch in the north and east portions of the region. Black cottonwood is found on alluvial sites throughout the area.

3.1 Distribution

Volume among Timber Supply Areas (TSA's) within the Kamloops Forest Region is unevenly distributed. Approximately 93% of the total hardwood volume occurs in the Kamloops and Okanagan TSA's (Table 3-1). These two TSA's account for 90% of the trembling aspen, 99% of the paper birch, and 82% of the black cottonwood total volume in the region. The discussion below focuses on the hardwood inventory in the Kamloops and Okanagan TSA's since they contain the highest concentration of hardwoods and the greatest volume of paper birch and black cottonwood.

Kamloops TSA

The highest proportion of hardwoods in the Kamloops Region occurs in the Kamloops TSA, where they constitute 74% of the total hardwood inventory in the region. Sixty-four percent of the Kamloops TSA inventory consists of trembling aspen, 34% of paper birch, and 2% of black cottonwood. Although paper birch is only about half the volume of aspen, it occupies the most productive and accessible land in the TSA. Paper birch is most abundant in the North Thompson and Adams River drainages.

Okanagan TSA

The Okanagan TSA represents 19% of the total hardwood inventory in the Kamloops Region. In contrast to the Kamloops TSA, paper birch is more abundant than trembling aspen. Fifty-nine percent of the inventory consists of paper birch, 35% of aspen, and 6% of black cottonwood. Extensive stands of paper birch are located in the proximity of Shuswap Lake, Mabel Lake, Mara Lake, Sugar Lake, the Monashee Mountains, and the Okanagan Highland.

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[1] Close utilization standards are 12.5 cm+ dbh to 10 cm top, minus decay, waste and breakage.

TABLE 3-1. Total volume (MM m^3) of hardwoods in each TSA in the Kamloops Forest Region

TSA	Aspen	Birch	Black cotton-wood	Total deciduous	Total conifers	% deciduous
Kamloops	6.03	3.13	0.21	9.37	264.98	3.41[a]
Okanagan	0.83	1.39	0.14	2.36	185.45	1.26
Merritt	0.60	0.00	0.04	0.64	161.53	0.40
Lillooet	0.16	0.07	0.03	0.26	88.82	0.29
Total	**7.62**	**4.59**	**0.42**	**12.63**	**700.78**	**1.77**
Percent of total volume	**1.07**	**0.64**	**0.06**	**1.77**	**98.23**	

[a] Error due to rounding.

3.2 Stand Composition

Stand composition — that is, the proportion of each species located in different forest types — is important to the commercial feasibility of harvesting a stand. As the proportion of hardwood species increases, the feasibility of harvesting may increase or decrease depending on whether objectives are to use hardwoods, conifers or both. The preponderance of relatively pure stands of trembling aspen, paper birch and black cottonwood in the southern Interior favours hardwood use.

The B.C. Ministry of Forests has identified 42 type groups of tree species composition in the Kamloops Region. Of the 42 groups, 5 are composed predominantly of deciduous species. In the Kamloops TSA, 61% (5.75 MM m^3) of the total deciduous volume (9.37 MM m^3) falls within the five deciduous type groups. These cover an area of 56 449 ha, which constitutes approximately 4.5% of the total TSA land base. Sixty-nine percent of their volume is classified as aspen (type groups 41 and 42), 29% as birch (type group 40), and 2% as cottonwood (type groups 35 and 36) (Table 3-2). The remaining 39% of the deciduous volume in the Kamloops TSA falls within type groups that are dominated by coniferous species. The Okanagan TSA inventory has yet to be updated to include the breakdown by type group.

TABLE 3-2. Deciduous type groups in the Kamloops TSA

Code	Name	Dominant species	Associated group	Volume (MM m^3)	Area (ha)
35	Cot Conif	Black cottonwood	Coniferous	0.05	314
36	Cot Decid	Black cottonwood	Deciduous	0.10	759
40	Bi	Birch	Any	1.64	11 855
41	A Conif	Aspen	Coniferous	2.36	26 204
42	A Decid	Aspen	Deciduous	1.59	17 317
Total				**5.74**	**56 449**

3.3 Age Class

Paper birch and black cottonwood reach maturity by 50–70 years. Many hardwood stands in the Kamloops Region are mature or over-mature because they have been little used. As a result, decay is high and the stems generally are of low quality.

The hardwood inventory for the Kamloops TSA has been broken into two age classes: (1) younger than 80 years (immature); and (2) older than 80 years (mature). The Okanagan TSA inventory has yet to be updated to include the breakdown by age class. Considering the biological rotation of the hardwood species in question, the age classes "immature" and "mature" should more appropriately be named "maturing" and "over-mature," respectively. Table 3-3 summarizes the "maturing" and "over-mature" volume of deciduous species in the Kamloops TSA.

TABLE 3-3. Volume (MM m^3) of hardwood species by stand/age class in the Kamloops TSA

Species	Maturing (<80 yr)	% Maturing	Over-mature (>80 yr)	% Over-mature
Aspen	3.51	58	2.52	42
Birch	1.94	62	1.20	38
Cottonwood	0.08	40	0.12	60
Total	**5.53**	**59**	**3.84**	**41**

4 RESULTS OF IMMATURE-MATURE STAND ASSESSMENTS

We assessed immature-mature stands on productive sites in terms of stand structure, species composition, and growth and yield. With that information, growth and yield expectations for managed stands can be estimated.

4.1 Site Characteristics

The sites assessed in the ICH and IDF zones are described in Tables 4-1 and 4-2, respectively. Within biogeoclimatic variants, sites were sorted according to moisture regime and site history (most recent disturbance). Where possible, a range in moisture regime from subxeric to hygric was sampled. Only three types of site history were encountered: wildfire, selective cut, and clearcut.

There was little difference in site characteristics among stands sampled in different biogeoclimatic units.

Subxeric

Four subxeric sites were sampled. All stands on these sites had a history of wildfire. A few scattered old-growth Douglas-fir in the IDFmw1 stand also had been selectively removed.

Slopes on subxeric sites were consistently steep (65–80%) and occupied mid-slope positions. Soils were rapidly drained coarse sands over colluvial veneer. The humus form was Mor, averaging 0.8 ± 1.5 cm in depth (range: 0–3 cm).

TABLE 4-1. Description of sites assessed in the ICH zone

Variant	Moisture regime[a]	Site history[b]	Elev. m	Slope %	Aspect	Slope position	Humus form[c]	Organic depth cm	Drain class[d]	Texture[e]	Terrain class[f]	Stand age
ICHmw3 (Thompson)	SX	F	400	65	NW	Mid	MR	0	R	SL	CV	70
	SX	F	380	65	S	Mid	MR	0	R	S	CV	40
	SM	F	490	20	E	Lower	ML	1	R	S	FB	50
	SM	S	350	20	S	Lower	MD	4	R	S	MB	60
	M	F	400	5	SE	Mid	ML	5	W	SL	MB	52
	M	S	550	10	N	Mid	ML	9	W	SL	MB	100
	SHG	C	380	0	S	Toe	ML	0	P	C	MB	50
	HG	F	700	0	S	Dep	ML	15	P	SCL	FB	53
ICHmw2 (Shuswap)	SX	F	800	70	SW	Mid	MR	0	R	S	CV	20
	SM	S	750	27	W	Mid	MD	4	W	SCL	MB	56
	M	S	400	20	E	Mid	ML	4	MW	L	MB	75
	M	C		15	N	Mid	MR	3	R	LS	MB	47
	SHG	F	700	0	NW	Toe	ML	3	P	CL	FB	20
	SHG	S		2	W	Toe	ML	10	P	C	MB	70
	HG	F		0	S	Dep	ML	20	P	C	FB	80

TABLE 4-2. Description of sites assessed in the IDF zone

Variant	Moisture regime[a]	Site history[b]	Elev. m	Slope %	Aspect	Slope position	Humus form[c]	Organic depth cm	Drain class[d]	Texture[e]	Terrain class[f]	Stand age
IDFmw2 (Thompson)	SM	F	400	50	E	Mid	ML	3	R	LS	CV	47
	M	F	500	18	W	Mid	ML	7	W	SL	MB	43
	M	C	600	15	W	Mid	ML	5	MW	SCL	MB	40
	M	C	500	18	E	Mid	ML	5	MW	SCL	MB	80
	SHG	C	350	0	S	Toe	ML	0	W	SL	FB	65
	SHG	C	360	0	S	Toe	ML	3	R	S	FB	63
IDFmw1 (Shuswap)	SX	S		80	NE	Mid	MR	3	R	S	CV	52
	SM	S	350	35	W	Mid	MR	0	R	SL	CB	80
	M	S		5	SW	Mid	ML	1	W	SL	MB	80
	M	S	520	20	E	Mid	ML	2	MW	SL	MB	35
	SHG	S	520	5	S	Dep	ML	0	P	CL	MB	40

[a] SX = subxeric, SM = submesic, M = mesic, SHG = subhygric, HG = hygric.
[b] F = wildfire, S = selective cut, C = clearcut.
[c] MR = mor, MD = moder, ML = mull.
[d] R = rapid, W = well, MW = moderately well, P = poor.
[e] S = sand, C = clay, L = loam.
[f] CV = colluvial veneer, CB = colluvial blanket, MB = morainal blanket, FB = fluvial blanket.

Submesic

Five submesic sites were sampled. All had a history of fire and two had evidence of selective cutting.

Slopes on submesic sites were considerably more shallow (20–50%) than subxeric sites and occupied mid- to lower slope positions. Soils were rapidly to well-drained sands to sandy loams. Terrain was variable and included colluvial, morainal and fluvial blankets. The humus form also was variable and included Mor, Moder and Mull. Organic matter depth averaged 2.4 ± 1.8 cm (range: 0–4 cm).

Mesic

Nine mesic sites were sampled. Site history was variable and included wildfire (two sites), clearcutting (three sites), and selective cutting (four sites).

Slopes on mesic sites ranged from 5 to 20% and consistently occupied mid-slope positions. Soils were well to moderately well-drained sandy loams and sandy clay loams over morainal blankets. The humus form was generally Mull and organic matter depth averaged 4.6 ± 2.5 cm (range: 1–9 cm).

Subhygric

Six subhygric sites were sampled. As with mesic sites, site history was variable, including wildfire (one site), clearcutting (three sites), and selective cutting (two sites).

Slopes were generally flat, ranging from 0 to 5%, and occupied toe slope positions adjacent to rivers. Soils were either poorly drained clays and clay loams over morainal blankets, or well to rapidly drained sands and sandy loams over fluvial blankets. The humus form was consistently Mull and generally the organic matter was shallow. With the exception of one site (10 cm), organic matter depth averaged 0.6 ± 1.3 cm (range: 0–3 cm).

Hygric

Only two hygric sites were sampled, both located in the ICH zone. Site history was wildfire.

The hygric sites occurred in depressions adjacent to rivers. Soils were high in clay content and so were poorly drained. The terrain was fluvial blanket. The humus form was Mull and the organic matter was deep (17.5 ± 3.5 cm).

4.2 Species Composition and Stand Condition

Hardwood species composition (by volume) of sampled stands was similar among biogeoclimatic variants. It did vary considerably, however, among moisture regimes (Figure 4-1). Because the stands on subhygric and hygric sites were similar, they were evaluated together (as subhygric). In general, the proportion of birch decreased from dry (80% of the stand volume) to wet (20% of the stand volume) sites. Black cottonwood was virtually absent from subxeric and submesic sites and only of minor importance on mesic sites (10% of the stand volume). On subhygric and hygric sites, however, black cottonwood was clearly the dominant species (70% of the stand volume). Trembling aspen occurred in low abundance across the range of moisture regimes. It was most abundant on subxeric sites (20% of the stand volume) and generally absent from subhygric and hygric sites (<1% of the stand volume).

Xeric and subxeric sites

Xeric sites were not sampled. However, hardwoods were generally absent from xeric microsites embedded within wetter moisture regimes.

On subxeric sites, birch made up approximately 80% and aspen 20% of the stand volume (Figure 4-2a). Birch was clearly dominant while aspen was restricted to isolated clumps. The majority of birch were multi-stemmed, suggesting that at least some originated from basal sprouts. Aspen was of sucker origin. Growth of both species was slow and condition poor due to basal scars from falling rock. The scars served as infection courts for fungi and many of the stems were infected with *Fomes ignareus*.

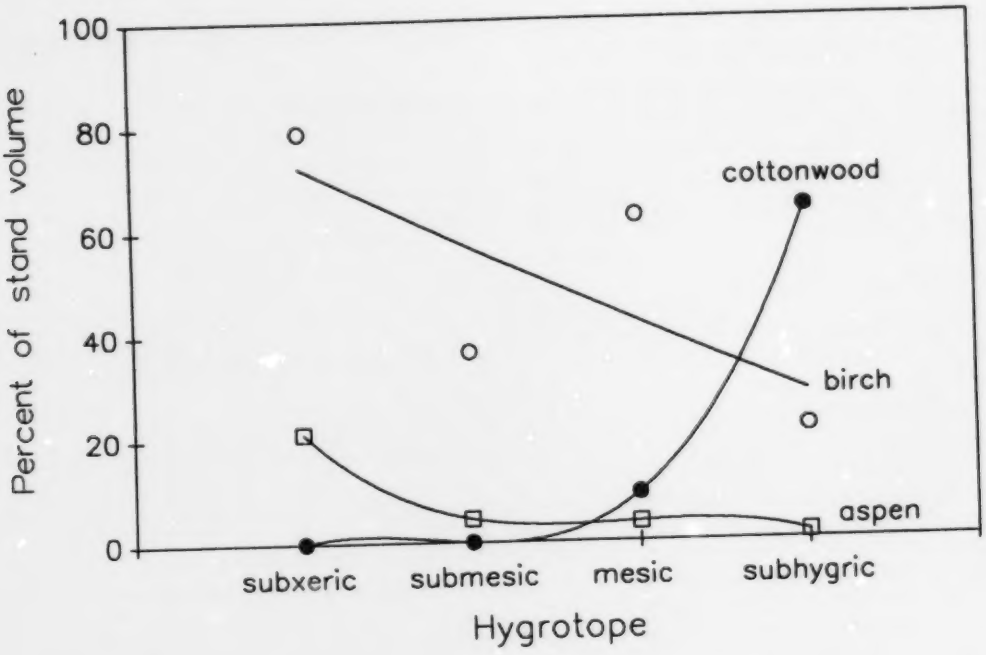

FIGURE 4-1. Hardwood species composition by volume across a range in hygrotope.

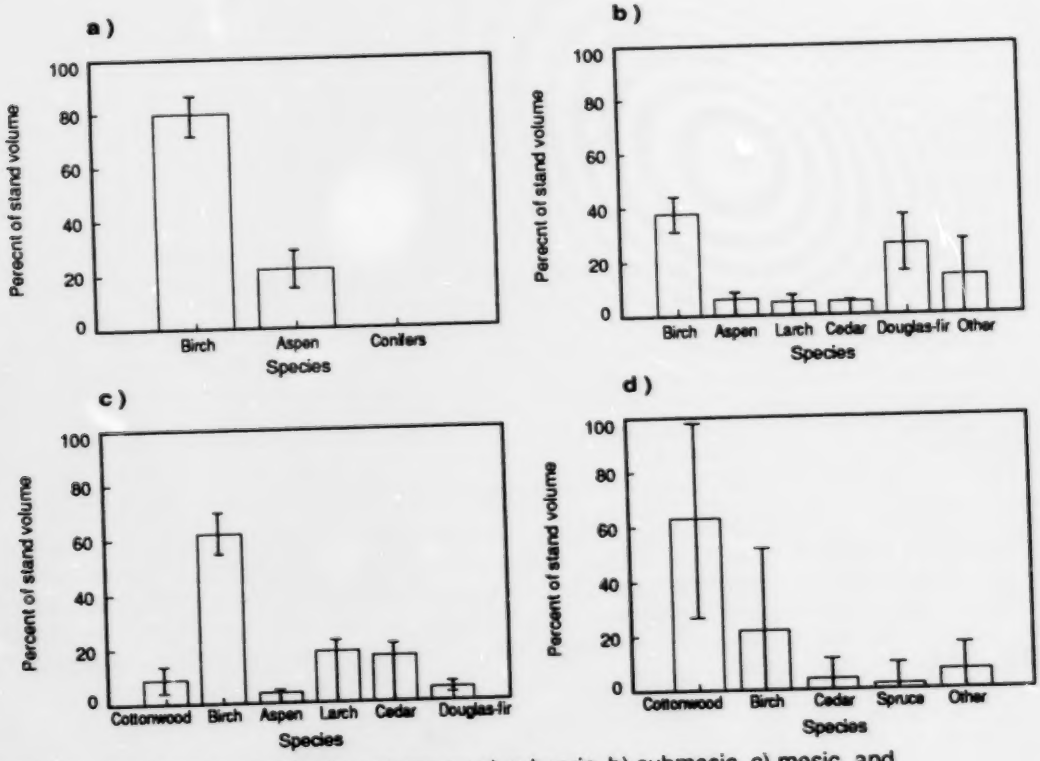

FIGURE 4-2. Species composition by volume on a) subxeric, b) submesic, c) mesic, and d) subhygric-hygric sites.

Conifers were generally absent. The dominant species were Douglas-fir and ponderosa pine, with minor amounts of lodgepole pine and western redcedar.

The understory was sparse on xeric and subxeric sites and varied according to biogeoclimatic zone. In the IDF zone, the shrub layer was dominated by *Paxistima myrsinites*, *Mahonia aquifolium*, *Rosa* sp. and *Symphoricarpos albus*, and the herb layer by *Calamagrostis rubescens*, *Aster conspicuus* and *Fragaria* sp. In the ICH zone, the dominant shrubs were *Paxistima myrsinites*, *Acer douglasii*, and *Rubus idaeus*. Herbs were virtually absent (except for *Cryptogramma crispa*) and mosses and lichens (*Cladonia* and *Peltigera*) were relatively abundant.

Submesic and mesic sites

Hardwood species composition on submesic and mesic sites was variable. The proportion of birch ranged from 30% on submesic sites to 70% on mesic sites (Figures 4-2a and 4-2b). The greater proportion on mesic than submesic sites was not a result of site suitability, but rather of the differences in the amount of selective logging that had occurred. The greater logging pressure on mesic sites resulted in more openings that were ideal for the seeding-in and basal sprouting of birch. Aspen accounted for a low (<5%) proportion of the stand volume on both mesic and submesic sites. Cottonwood was absent from submesic sites and apparently met its moisture requirements on mesic sites, where it formed approximately 8% of the stand volume. *Fomes ignareus* (heart rot) appeared in birch between 50 and 55 years of age.

Conifers formed a major component of stands on submesic and mesic sites. Whereas the majority of stands on dry and wet sites were predominantly hardwood, the majority on circum-mesic sites were mixed-wood. Birch often occurred in root disease (*Armillaria*) centres where conifers had died and left large gaps in the canopy. Conifer regeneration was also abundant in stands that had been selectively logged. The dominant conifers were Douglas-fir, western redcedar, and, in the Shuswap variants, western larch. Other species included western hemlock, lodgepole pine, western white pine and ponderosa pine.

The understory was also sparse on circum-mesic sites, particularly under relatively pure birch stands. In the IDF zone, the shrub layer was dominated by *Paxistima myrsinites*, *Rubus parviflorus*, *Mahonia aquifolium*, *Rosa* sp., and *Symphoricarpos albus*. The herb layer was dominated by *Aster conspicuus*, *Linnea borealis*, *Chimaphila umbellata*, and *Pteridium aquilinum*. In the ICH zone, the dominant shrubs were *Paxistima myrsinites*, *Mahonia aquifolium*, and *Acer douglasii*. Herbs included *Chimaphila umbellata*, *Linnea borealis*, *Cornus canadensis*, *Tiarella unifoliata*, and *Clintonia uniflora*.

Subhygric-hygric sites

Cottonwood occurred either in pure stands or mixed with birch on subhygric and hygric sites (Figure 4-2d). It ranged in proportion from 0% (20-year-old site) to 100%, and averaged 64% of the stand volume. Birch ranged in proportion from 0% to 77% (20-year-old site) and averaged 22%. Whereas most cottonwood originated from seed, many birch originated from stump sprouts. Virtually all birch were multi-stemmed, even those that originated from seed (possibly as a result of early browsing). *Fomes ignareus* was present in birch and black cottonwood on all sites older than 50 years. Aspen was generally absent, except where clones were abundant on drier sites nearby.

Conifers formed a minor component of the stand volume on subhygric and hygric sites. The dominant conifers were the flood-resistant species, spruce and western red-cedar (Krajina *et al.* 1982). Others included western hemlock, western white pine, and Douglas-fir.

Understory composition varied according to biogeoclimatic zone. In the IDF zone, it consisted of a sparse shrub (*Acer douglasii* and *Symphoricarpos albus*) and herb (*Streptopus roseus* and *Equisetum* sp.) layer. In the ICH zone, the understory was lush and diverse. Shrub species included *Alnus viridis* ssp. *sinuata*, *Cornus sericea*, *Salix* sp., *Vacciniums* spp., and *Rubus parviflorus*. Herb species included *Ausarum caudatum*, *Tiarella unifoliata*, and *Cornus canadensis*.

4.3 Stand Density and Structure

The change in stand density, measured as number of stems per hectare and basal area per hectare over time, is illustrated in Figures 4-3 and 4-4, respectively. The number of stems per hectare decreased with age as a result of self-thinning. Growth was concentrated on fewer stems, which resulted in an increase in basal area with time. As moisture regime (and site quality) increased, so did stand density (Figure 4-4). In the oldest age class (>70 years), high quality sites supported up to seven times the basal area of poor quality sites.

The diameter distribution within stands on subxeric, mesic, and subhygric sites is summarized in Figures 4-5, 4-6 and 4-7, respectively. Both hardwood and conifer species are included. Diameter distributions within each moisture regime are shown for two age classes: 20–40 years and 50–70 years. For mesic sites, however, the older age class represented is 70–100 years because of sampling bias.

Subxeric sites

The stands sampled on subxeric sites were even aged. Figure 4-5 shows the change from a highly skewed diameter distribution in 20- to 40-year-old stands, to a nearly normal distribution in 50- to 70-year-old stands, which is characteristic of even-aged stands. Whereas the majority of stems were in the 0–10 cm diameter class in the younger stands, most were in the 20–30 cm diameter class in the older stands. Little self-thinning appears to have occurred after 20–40 years because density (stems per hectare) was not significantly lower in the 50–70 year age class (Figure 4-3). Initial density on subxeric sites appears to have been sufficiently low that inter-tree competition did not result in a high degree of mortality. Consequently, most individuals survived and grew into the 20–30 cm diameter range that dominates the older age class (Figure 4-5).

Mesic sites

The stands sampled on mesic sites were even aged, although there was a tendency toward an uneven-aged stand structure in 70- to 100-year-old stands (Figure 4-6). This structure is a result of two phenomena: (1) selective cutting of a few, scattered individuals; and (2) development of canopy gaps due to root disease. New regeneration filled the gaps, resulting in a relatively high number of stems in the small diameter classes. The new regeneration was predominantly conifer, possibly because many of the canopy gaps were too small to meet birch's light requirements for survival.

Stand density in 20- to 40-year-old stands was considerably higher on mesic than subxeric sites (Figures 4-3 and 4-4). Inter-tree competition was more intense on mesic sites, and self-thinning significantly reduced density at maturity. In addition, several individuals were in the 50–60 and 60–70 cm diameter classes on mesic sites, compared with none on subxeric sites (Figure 4-6). Better growth was presumably due to greater resource availability. Stand density in the 50–60 and >70 age classes was higher on mesic than subhygric sites. Conifers generally grow at a higher density than do hardwoods and, therefore, since a higher proportion of conifers occurred on mesic than subhygric sites, a greater number of stems grew on one hectare.

Subhygric sites

The stand structure on subhygric sites was similar to that on mesic sites (Figure 4-7). However, in stands 20–40 years old, the number of individuals in the 0–10 cm diameter class was considerably higher on subhygric (approximately 2500 stems per hectare) than on mesic (approximately 1500 stems per hectare) sites. Self-thinning was, therefore, more rapid and severe (Figure 4-3).

As stands on subhygric sites grew older, the diameter distribution changed from highly skewed (20–40 years) to normal (50–70 years). In contrast to the stands on mesic sites, few individuals on the subhygric sites occurred in the small diameter classes. The lack of small stems was a result of: (1) the younger age class sampled (50–70 years on subhygric sites versus 70–100 years on mesic sites) and hence a lower frequency of gaps, and (2) the low frequency of selective cutting on wetter ecosystems. Compared with drier ecosystems, the maximum diameter and number of trees in larger diameter classes were greater for stands on subhygric sites.

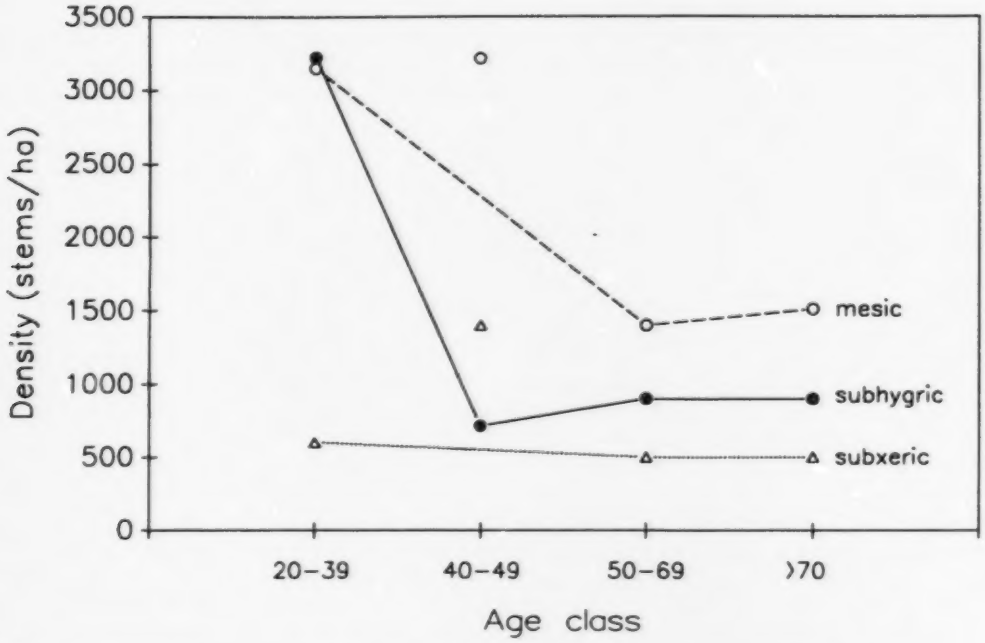

FIGURE 4-3. Change in hardwood density over time on subxeric, mesic and subhygric sites.

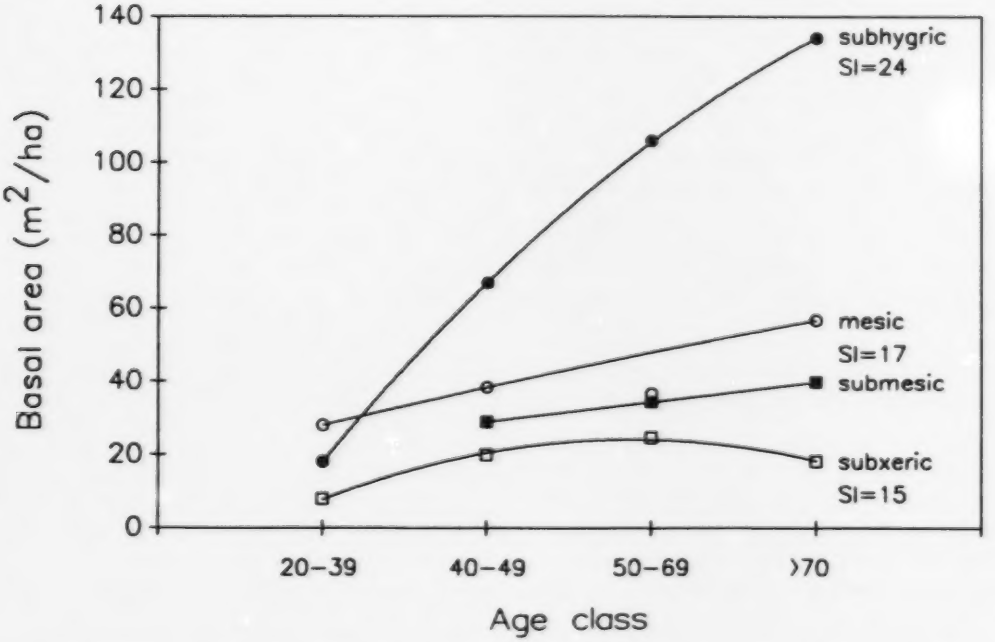

FIGURE 4-4. Change in total stand basal area over time on subxeric, submesic, mesic and subhygric sites.

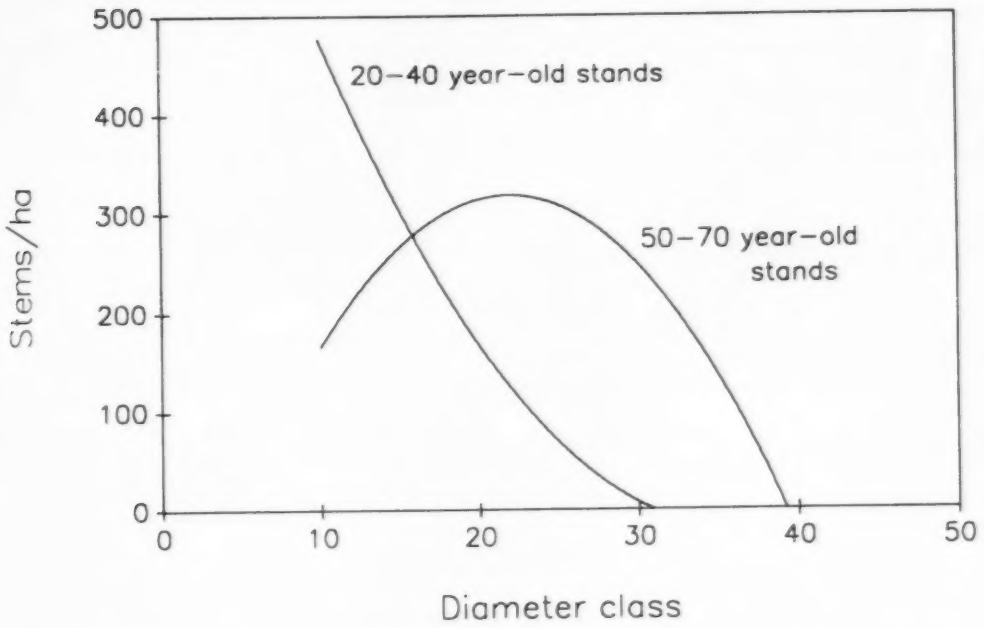

FIGURE 4-5. Diameter distribution (cm) of hardwood-dominated stands on subxeric sites.

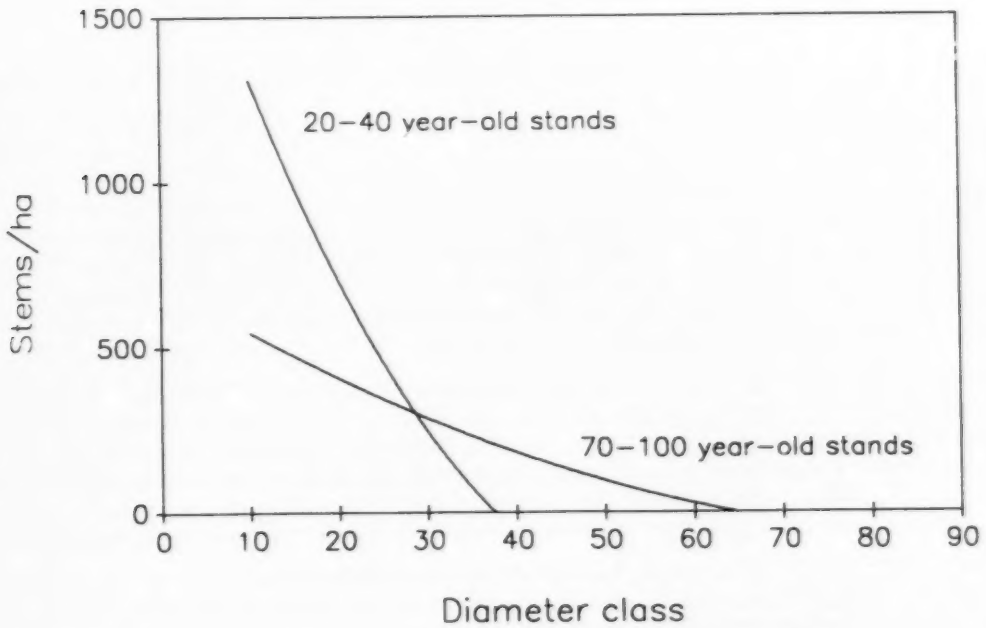

FIGURE 4-6. Diameter distribution (cm) of hardwood-dominated stands on mesic sites.

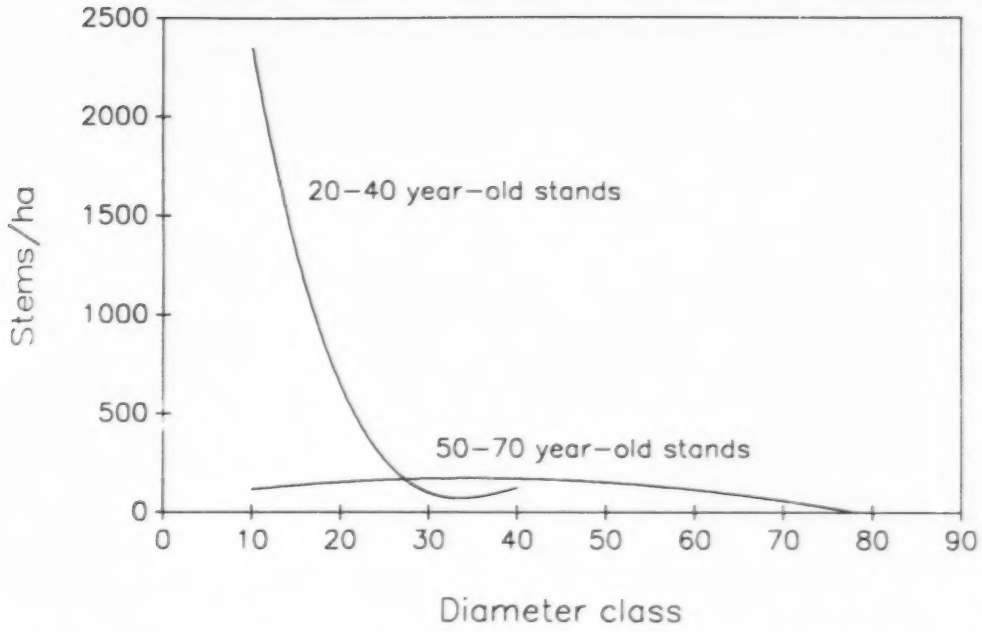

FIGURE 4-7. Diameter distribution (cm) of hardwood-dominated stands on subhygric sites.

4.4 Site Index

Site index equations developed by Inventory Branch of the B.C. Ministry of Forests (1986) were used to calculate the site index at age 50 for birch, black cottonwood, and trembling aspen. Table 4-3 summarizes the mean, range, and standard error of site index values for the range of moisture regimes and biogeoclimatic variants sampled.

Only those trees for which age was determined are included in the table. Unfortunately, the sample size for each category is small.

Paper birch

In all biogeoclimatic variants sampled, the site index of paper birch increased with moisture availability (from subxeric to subhygric). Furthermore, site index values across the range of hygrotopes increased from the IDFmw2, to the ICHmw2, to the ICHmw3 variant. This trend corresponds with an increase in average annual precipitation from 521 mm in the IDFmw2 to 656 mm in the ICHmw2, and 671 in the ICHmw3 (Lloyd *et al.* 1990). The difference in site index between the two ICH variants may be due to differences in the amount of precipitation that falls during the growing season (243 mm in the ICHmw2 vs. 292 mm in the ICHmw3).

Site index values were compared among hygrotopes and ICH variants in Figure 4-8. Birch reached its greatest productivity on subhygric sites in the ICHmw3 (Thompson) variant. There, sites were classed as good when compared with site index values published in British Columbia (B.C. Ministry of Forests 1986) and the northeastern United States (Solomon and Leak 1969). Similarly, submesic-mesic sites in the ICHmw3, submesic-subhygric sites in the ICHmw2, and subhygric sites in the IDFmw2 were classed as medium. Subxeric sites in the ICH variants and subxeric-mesic sites in the IDFmw2 variant were classed as poor.

Site index values measured on subxeric-mesic sites in the IDFmw1 were higher than those in any other zone or variant. Average annual precipitation is lower (515 mm), however, compared with the other variants. The small sample size clearly limits the reliability of those values.

TABLE 4-3. Site index$_{(50)}$ values for birch, black cottonwood and trembling aspen

Species	Variant	Subxeric	Submesic	Mesic	Subhygric
Paper birch	ICHmw3	16.4[a] (0.1)[b] (16.3-16.4)[c] n=2[d]	18.0 (1.6) (14.4-20.9) n=4	18.9 (0.8) (17.0-20.1) n=4	28.9 (1.6) (27.8-30.0) n=2
	ICHmw2	12.8 (1.8) (7.6-16.0) n=5	23.3 (11.0-22.4) n=1	18.0 (1.7) (17.9-24.3) n=8	22.1 (1.5) n=4
	IDFmw2	—	16.0 (0.5) (15.0-16.8) n=3	14.6 (1.1) (9.2-19.4) n=9	22.0 (2.6) (17.5-25.5) n=3
	IDFmw1	18.5 (0.1) (18.4-18.6) n=2	20.6 n=1	23.8 (2.2) (21.6-23.8) n=2	—
Black cottonwood	ICHmw3	—	—	—	30.9 (3.1) (24.7-34.9) n=3
	ICHmw2	—	—	—	29.6 n=1
	IDFmw2	—	—	—	30.6 (1.4) (26.4-36.6) n=6
	IDFmw1	—	—	—	27.1 (1.6) (25.5-28.6) n=2
Trembling aspen	ICHmw3	—	—	15.9 n=1	29.0 n=1
	ICHmw2	20.2 (6.5) (7.2-26.7) n=3	—	—	—
	IDFmw2	—	18.3 n=1	20.0 (0.6) (19.3-20.6) n=2	—
	IDFmw1	—	—	—	—

[a] Mean.
[b] Standard error.
[c] Range.
[d] Sample size.

Black cottonwood

Height of black cottonwood was measured only on subhygric-hygric sites, since the species was of minor importance in the drier ecosystems. Site index values did not differ among the ICHmw3, ICHmw2, and IDFmw2 variants, but they were lower in the IDFmw1 variant. When compared against site index values published by the B.C. Ministry of Forests (1986), black cottonwood on all sites was classed as good.

Trembling aspen

Patterns in site index among biogeoclimatic variants and hygrotopes were not apparent from the data collected, except that the tallest aspen grew on subhygric sites in the ICHmw3 variant. The lack of an identifiable pattern is attributed to inadequate sampling. When compared with the site index curves published

by the B.C. Ministry of Forests (1986), the site index on the ICHmw3 subhygric site was at the top of the range for good sites. Unfortunately, aspen on those sites is very sparse. Aspen measured in the other hygrotopes and variants was classed as medium.

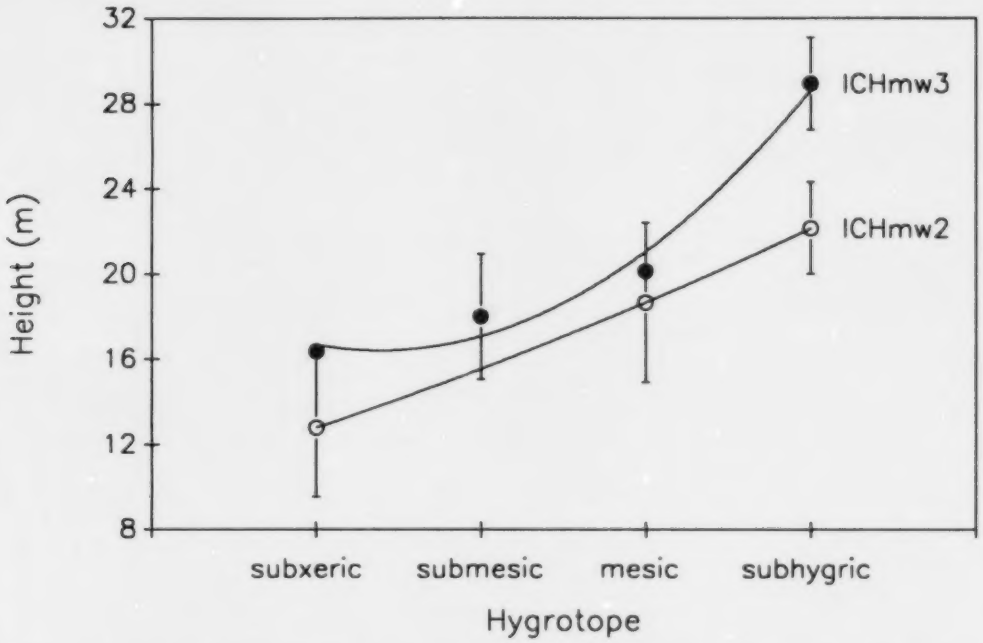

FIGURE 4-8. Comparison of birch site index (age 50) among hygrotopes in the ICHmw2 and ICHmw3 variants.

4.5 Growth and Yield

In this analysis, growth is described as mean annual increment (MAI) (m^3/ha per year) and yield as volume (m^3/ha). Stem volume was measured as total (30 cm stump height, 1 cm top diameter and 2 m log length) and merchantable (30 cm stump height, 10 cm top diameter and 5 m log length) (Kozak 1989). Mean annual increment (average annual increase in volume) was derived by dividing total stem volume by age.

Stand age is related to average site index, number of trees, basal area, total volume, merchantable volume, and MAI for the range of hygrotopes (subxeric- subhygric) in Table 4-4. Data from all variants was combined. Although the error of estimate was high due to small sample sizes, several distinctive trends emerged.

Total stand volume increased from subxeric to subhygric sites (Figure 4-9). In the 50–69 age class, total volume on subhygric sites was 3.7 and 11.9 times greater than on mesic and subxeric sites, respectively. Whereas total volume increased from the 50–60 to the 70–100 age class on submesic and mesic sites, it decreased on subxeric and, particularly, subhygric sites. The difference in volume accretion among hygrotopes was due to species composition. Subhygric and subxeric stands were composed of relatively pure hardwoods for which the rotation age is assumed to be 50–55 years. This assumption is based on the incidence of heart rot and the culmination of MAI in that age class. Stands that were in the 70–100 year age class were thus over-mature and "breaking up." In contrast to subxeric and subhygric stands, submesic and mesic stands had a relatively high component of conifers, which have considerably longer rotation ages than hardwoods. Those stands therefore continued to increase in volume beyond 70 years.

TABLE 4-4. Yield table for stands sampled on subxeric, submesic, mesic and subhygric sites

Age class (yr)	Sample size	Average $SI_{(50)}$ (birch)	Density (stems/ha)	Basal area (m^2/ha)	Total volume (m^3/ha)	Merch. volume (m^3/ha)	MAI (m^3/ha per yr)
Subxeric							
20–39	1	15	600	7.9	17.8	8.0	0.9
40–49	1	15	1400	20.0	138.8	112.9	3.5
50–69	1	15	500	24.6	88.9	73.5	1.7
>70	1	15	500	18.2	133.8	106.1	1.9
Submesic							
20–39	0	17	—	—	—	—	—
40–49	2	17	1850 (919)[a]	28.9 (0.1)	149.0 (49.8)	104.6 (36.7)	3.0 (0.9)
50–69	2	17	2200 (354)	34.3 (2.1)	268.2 (24.7)	207.2 (16.4)	4.6 (0.6)
>70	1	17	950	39.8	378.2	349.3	4.7
Mesic							
20–39	1	17	3150	28.0	186.0	112.0	5.3
40–49	3	17	3125 (2368)	38.3 (6.1)	178.6 (53.1)	96.1 (27.4)	4.1 (1.1)
50–69	1	17	1400	36.6	290.0	234.8	5.5
>70	5	17	1510 (665)	56.8 (6.4)	456.8 (74.9)	414.2 (67.5)	5.9 (1.1)
Subhygric							
20–39	1	24	3225	18.1	92.6	34.0	4.6
40–49	2	24	713 (159)	66.7 (21.7)	435.1 (19.7)	392.7 (29.5)	9.7 (0.6)
50–69	3	24	900 (278)	105.9 (23.3)	1062.0 (229.7)	1017.0 (27.2)	18.3 (5.2)
>70	1	24	900	134.1	799.0	770.9	10.0

[a] Standard error.

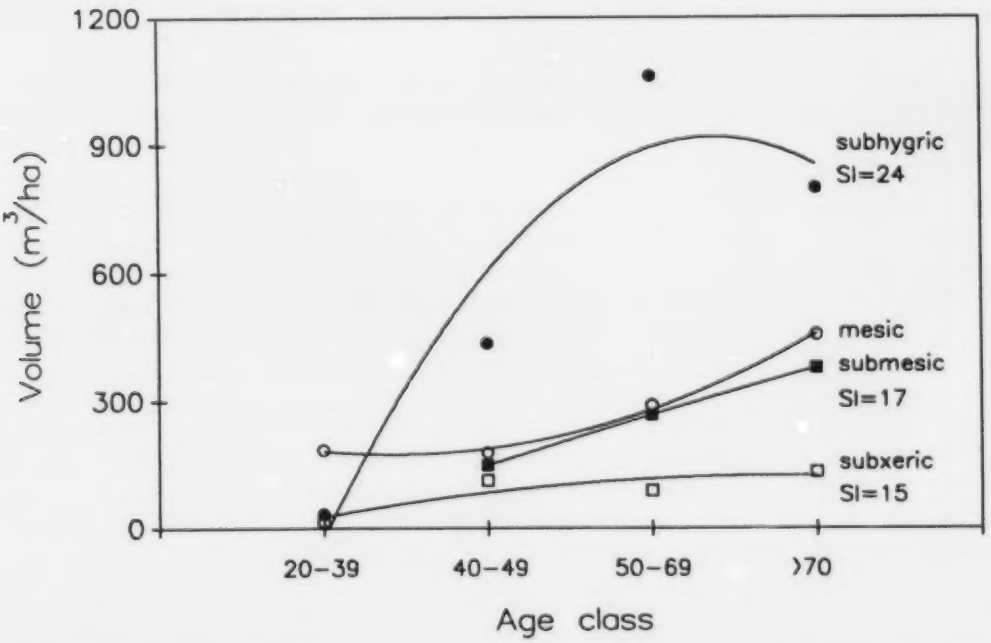

FIGURE 4-9. Change in total volume over time on subxeric, submesic, mesic and subhygric sites.

Trends in merchantable volume followed those in total volume. The proportion of total volume that was merchantable in stands older than 50 years, however, increased with hygrotope (site quality). Whereas only 81% (± 3%) of total stand volume was merchantable on subxeric sites, 86% (± 7%) and 96% was merchantable on mesic and subhygric sites, respectively. The merchantable volume estimates are very high, however, compared with lumber recovery factors (30–50%) reported by others. Furthermore, the proportion of merchantable lumber increased with stand age: 47% (± 12%) at 20–39 years, 74% (± 16%) at 40–49 years, 84% (± 8%) at 50–69 years, and 90% (± 7%) at greater than 70 years. Realistically, the recovery of merchantable volume should decrease from the 50–70 to the >70 age class due to decay.

Mean annual increment increased as moisture availability increased (Figure 4-10). The increase was small from subxeric to mesic sites and substantially greater from mesic to subhygric sites, particularly in the 51–100 year age class. Clearly, the greatest potential for growing birch and cottonwood is on sites wetter than mesic.

Culmination of MAI on subhygric sites occurred at an average of 18.3 m^3/ha per year in the 50–69 age class (Figure 4-11). Culmination was not evident, however, within 100 years on submesic and mesic sites either because of the high proportion of conifers in the stands, or because of inadequate sampling in the 50–69 age class. In the oldest age class (>70 years), MAI on mesic sites averaged 5.9 m^3/ha per year. Culmination of MAI on subxeric sites occurred at 3.5 m^3/ha per year in the 40–49 age class. The early age of culmination on subxeric sites was a result of the high hardwood composition and early decay caused by stem damage from falling rock.

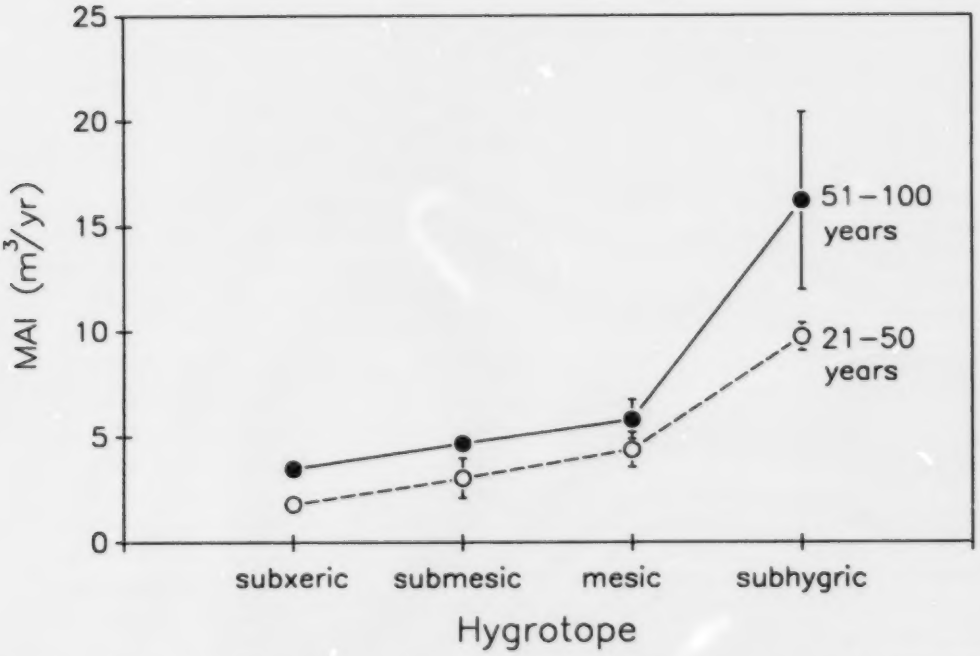

FIGURE 4-10. Comparison of mean annual increment of hardwood-dominated stands in 21–50 and 51–100 age classes among hygrotopes.

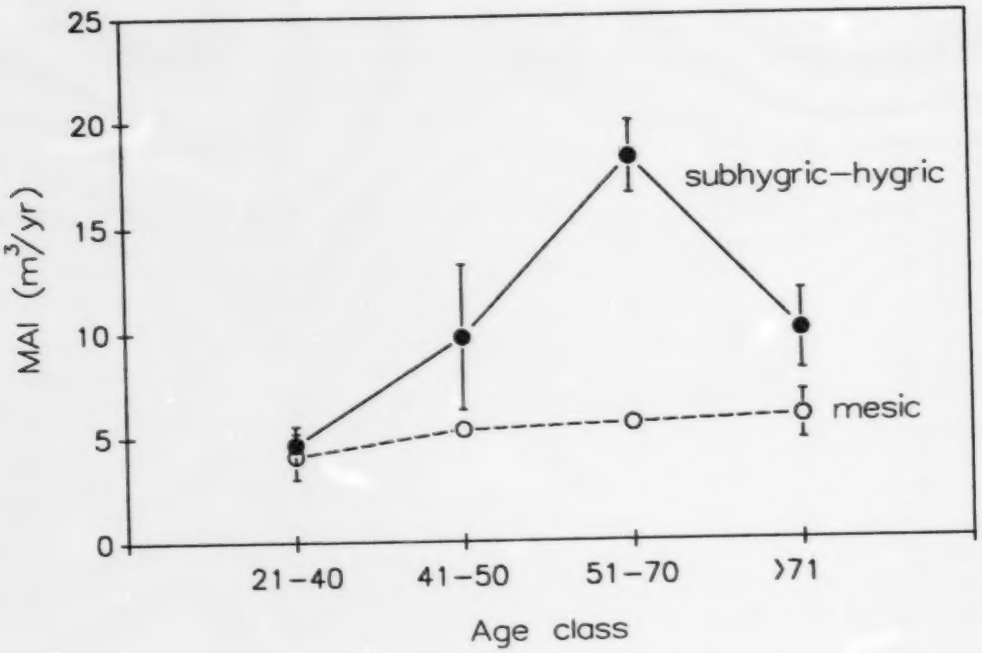

FIGURE 4-11. Comparison of mean annual increment of hardwood-dominated stands by age class between mesic and subhygric-hygric sites.

5 RESULTS OF REGENERATION STAND ASSESSMENTS

To identify which management practices are successful for hardwood, conifer or mixedwood production, regeneration stands (younger than 20 years) on productive sites were assessed in terms of growth, density, and stocking of hardwoods and conifers.

5.1 Description of Field Sites

The regeneration sites assessed are described in Table 5-1. Within biogeoclimatic variants, sites were sorted according to moisture regime and site preparation treatment. Three types of site preparation treatments were encountered: none (N), mechanical bunch-and-burn (M), and broadcast burn (B). Each site was rated according to burn severity, ranging from 0 (no impact) to 3 (severe impact).

Eighty-six percent of the sites assessed were submesic or mesic, which is where most of the logging occurs in the ICHmw subzone.[2] Ecological characteristics of stands on different hygrotopes are not described in this section because most sites assessed were circum-mesic, and species composition and environmental characteristics for each hygrotope were similar to those described for immature and mature stands in Section 6. This section describes treatments that are successful for hardwood and conifer regeneration. Sites are therefore described and classified according to treatment regime.

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[2] Mather, J. 1988. Assessment of silvicultural practices used in the Interior Cedar Hemlock zone of the southern interior: ICHm2, b, and v subzones: Salmon Arm, Vernon and Revelstoke Districts. B.C. Min. For., Kamloops, B.C., FRDA Project 3.47, Unpubl. report.

TABLE 5-1. Description of regeneration sites assessed

Variant	Moisture regime[a]	Harvest year	Site prep.[b]	Site prep. delay	Planted species[c]	Planting delay	Plantation age	Elev. m	Slope %	Aspect	Texture[d]	Organic depth
ICHmw3 (Thompson)	SM	80	N (0)	–	–	–	–	725	30	SE	SL	20
	SM	83	B (1)	1	–	–	–	400	25	E	LS	5
	M	74	M (2)	2	S	1	12	850	15	NW	LS	6
	M	78	M (2)	1	F	2	8	770	10	E	SL	15
	M	79	M (3)	5	–	–	–	800	10	SE	SiS	5
	M	80	M (1)	0	F	2	7	500	15	NE	SL	5
	M	72	B (2)	2	F	9	6	770	10	E	SL	15
	M	74	B (1)	0	F	4	11	800	25	E	SL	4
	M	76	B (3)	3	S	3	7	800	60	E	SL	10
	M	77	B (3)	2	Pl	3	7	800	60	E	SL	2
	M	79	B (2)	1	F	1	8	950	10	S	SL	5
	M	79	B (2)	0	S	3	7	790	0	S	SiL	10
	SHG	73	M (0)	2	S	3	13	700	10	S	S	20
	SHG	74	B (1)	0	F	4	11	800	25	E	SL	10
	SHG	76	B (1)	3	F	3	7	500	0	E	SL	20
ICHwk1 (Thompson)	M	82	B (2)	1	F	1	5	850	10	SE	SL	5
ICHmw2 (Shuswap)	SM	70	B (2)	1	F,Pl	3	15	1150	15	S	L	1
	SM	74	B (1)	0	F	10	6	450	40	SW	SL	1
	SM	87	B (3)	1	F	1	1	450	30	SW	SL	1
	M	81	N (0)	–	–	–	–	1000	35	N	SL	5
	M	73	M (3)	3	F	2	11	650	10	W	SL	1
	M	74	B (2)	2	F	4	12	1000	10	SE	L	6
	M	74	B (1)	0	F	10	6	450	15	SW	SL	10
	M	76	B (2)	1	F	5	7	800	3	W	SL	3
	M	78	B (1)	2	F	2	7	550	20	E	L	5
	M	79	B (3)	1	L	3	6	725	5	SE	L	1
	HG	82	N (0)	–	–	–	–	650	0	SE	C	6
IDFmw2 (Thompson)	M	77	N (0)	–	–	–	–	550	60	SE	LS	2
	M	78	M (0)	0	F	3	8	1000	30	SE	SL	6
	M	78	M (0)	1	F	2	8	850	10	SE	L	1
	M	76	B (2)	1	F	1	11	700	20	SE	SL	10
	M	80	B (1)	3	F	1	5	650	30	NW	SL	–
	M	83	B (1)	0	F	5	1	750	15	NW	L	12
	SHG	76	B (1)	1	F	1	11	700	0	SE	SiL	25

[a] SX = subxeric, SM = submesic, M = mesic, SHG = subhygric, HG = hygric.
[b] N = none, M = mechanical bunch-and-burn, B = broadcast burn; bracketed values are burn severity: 0 = none, 1 = light, 2 = moderate, 3 = severe.
[c] Planted species are: F = Douglas-fir, S = Engelmann spruce, Pl = lodgepole pine, L = western larch.
[d] S = sand, C = clay, L = loam, Si = silt.

Eleven percent of the sites received no site preparation treatment; the remainder were either mechanically bunched-and-burned (22%) or broadcast burned (77%). In most cases, the difference in impact between broadcast and mechanical burn treatments was hard to discern. For this reason, treatments were distinguished by burn severity rather than the actual treatment cited on the history record. The delay between harvest and site preparation treatment ranged between 0 and 3 years and did not increase or decrease from the early 1970's to the mid-1980's. Eighty-three percent of the sites assessed were planted to Douglas-fir (61%), Engelmann spruce (11%), lodgepole pine (6%), or western larch (3%). The delay between planting and site preparation decreased from an average of 5 years between 1970 and 1975 to an average of 2 years between 1980 and 1987.

5.2 Juvenile Height Growth of Hardwoods

Juvenile height growth of hardwoods far exceeded that of conifers. On mesic sites in the ICHmw3, for example, planted Douglas-fir seedlings were immediately over-topped by birch. By age 8, birch sprouts averaged approximately 4 m and Douglas-fir only 1 m in height (Figure 5-1).

Birch

Birch stems of sprout origin grew at a faster rate than those of seed origin (Figure 5-2). On mesic sites in the ICHmw3 variant, birch sprouts were 7 m tall and seedlings only 4 m tall at the age of 10. Similarly, on mesic sites in the ICHmw2 variant, sprouts were 6 m tall and seedlings 2 m tall at the age of 10. The difference in height growth rate between sprouts and seedlings decreased with time, particularly after age 10. Nevertheless, sprouts maintained about a 2 m height advantage over seedlings at least to the age of 1[illegible] in both variants.

Birch sprout and seedling height growth increased with moisture availability. It was fastest on subhygric and slowest on submesic sites. At age 10, sprouts were almost 10 m tall on subhygric sites and only 4 m tall on submesic sites in the ICHmw3 (Figure 5-3). Birch height growth also increased from the driest (IDFmw2) to the wettest (ICHmw3) of the variants assessed (Figure 5-4). Ten-year-old sprouts on mesic sites were only about 4 m tall in the IDFmw2 compared with 7 m tall in the ICHmw3.

Cottonwood

As with birch, cottonwood stems of sprout origin grew at a faster rate than those of seed origin (Figure 5-5). On mesic sites, cottonwood sprouts averaged 5.5 m and seedlings only 3.9 m tall at the age of 10. Growth was considerably faster on subhygric sites; sprouts were 13 m and seedlings 8 m tall at the age of 10 (Figure 5-6).

Cottonwood sprouts were taller on average than birch sprouts on both mesic and subhygric sites at age 10. On mesic sites, cottonwood was 5–8 m and birch only 4–7 m tall. On subhygric sites, cottonwood was over 3 m taller than birch.

Aspen

Little data was collected on height growth of aspen because of its sparsity in the study areas. Aspen suckers grew to an average of 7 m in 10 years on mesic sites (Figure 5-7). Growth was similar to that of birch but inferior to that of cottonwood.

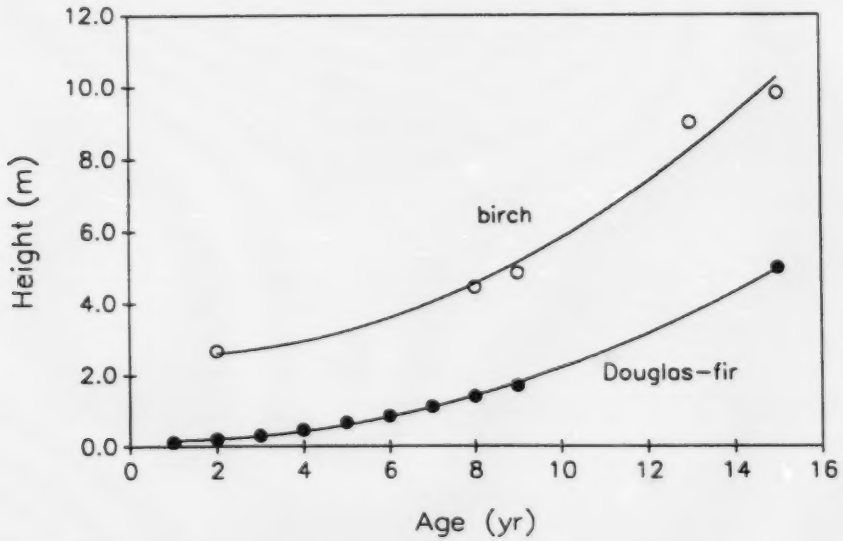


FIGURE 5-1. Comparison of height growth between birch sprouts and Douglas-fir on mesic sites in the ICH zone.

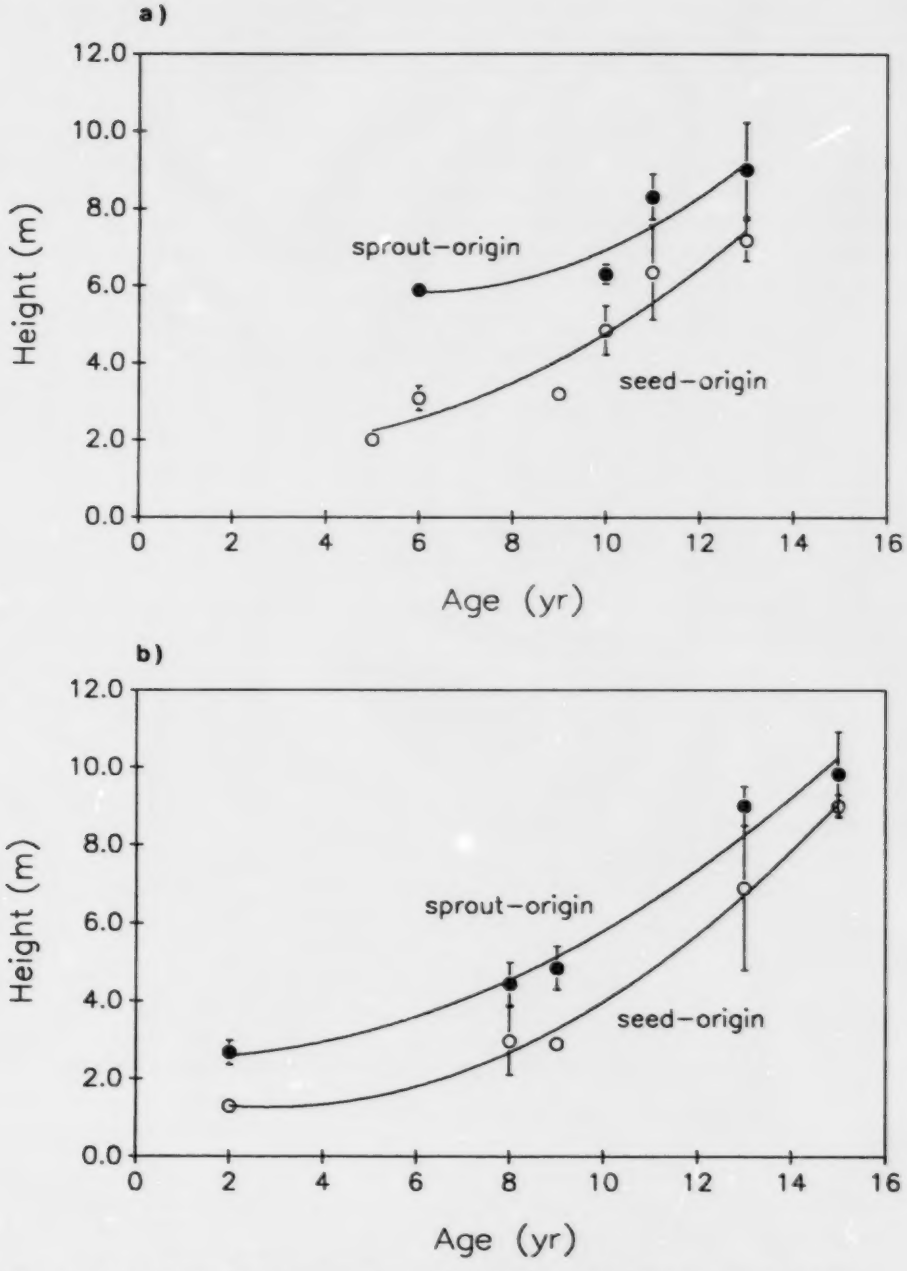


FIGURE 5-2. Birch height growth on mesic sites in the a) ICHmw3 and b) ICHmw2 variants.

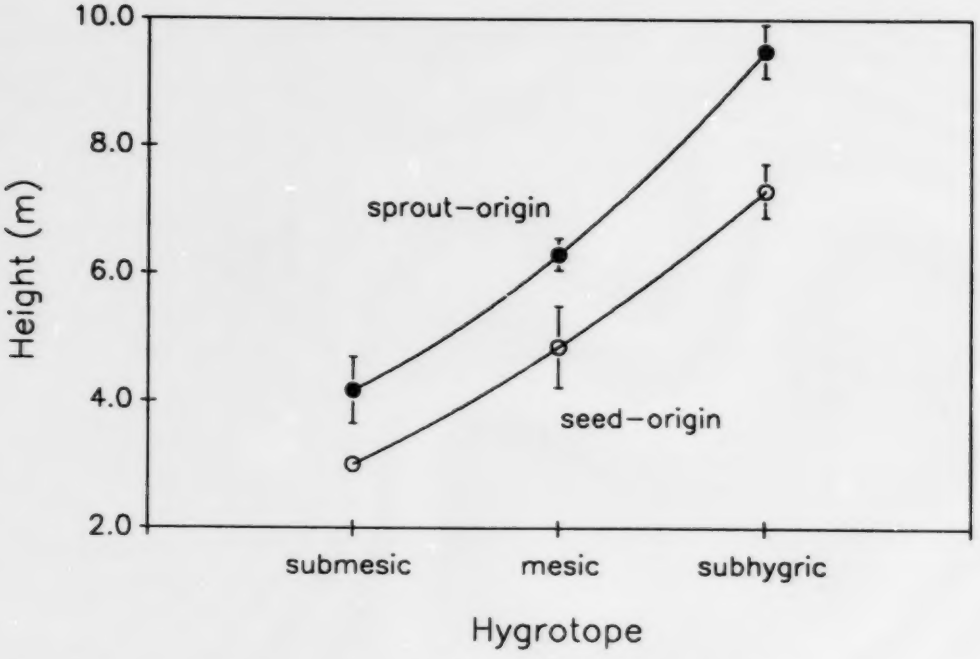


FIGURE 5-3. Height growth of sprout origin and seed origin birch by hygrotope.

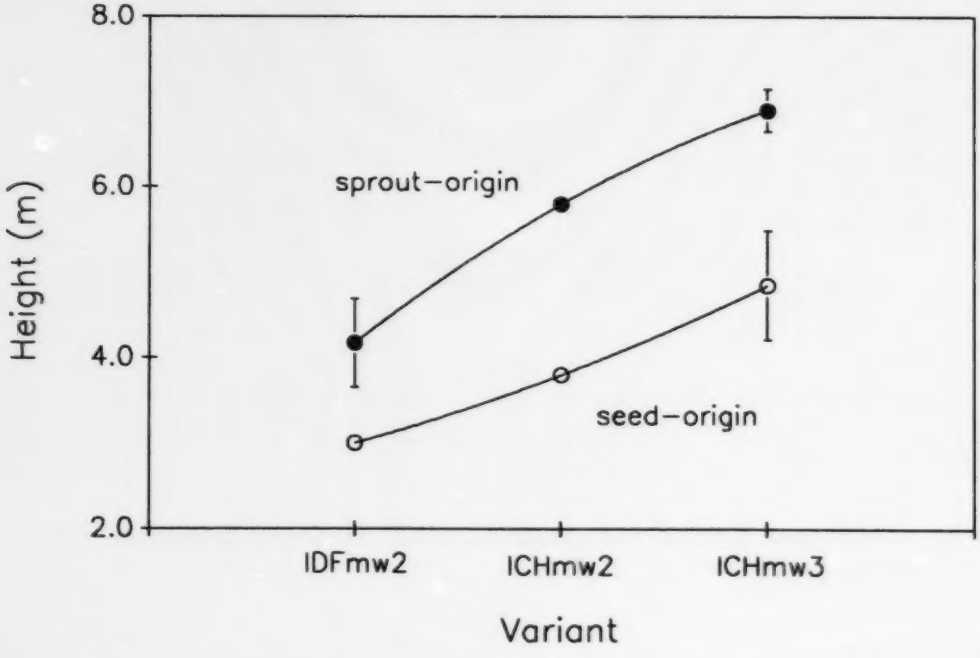


FIGURE 5-4. Comparison of seed origin and sprout origin of 10-year-old birch among IDFmw2, ICHmw2 and ICHmw3 variants.

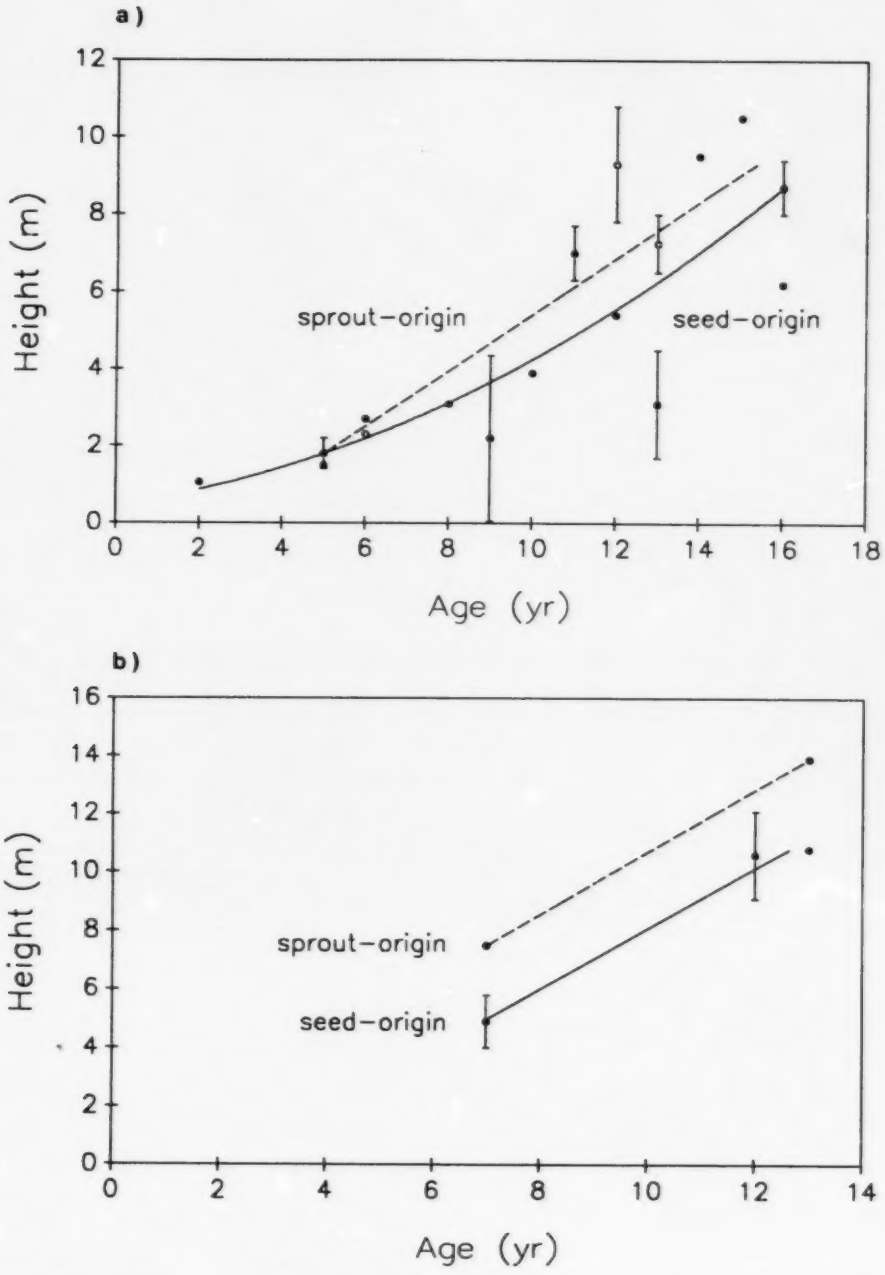


FIGURE 5-5. Height growth comparison of sprout origin and seed origin of cottonwood on a) mesic and b) subhygric sites.

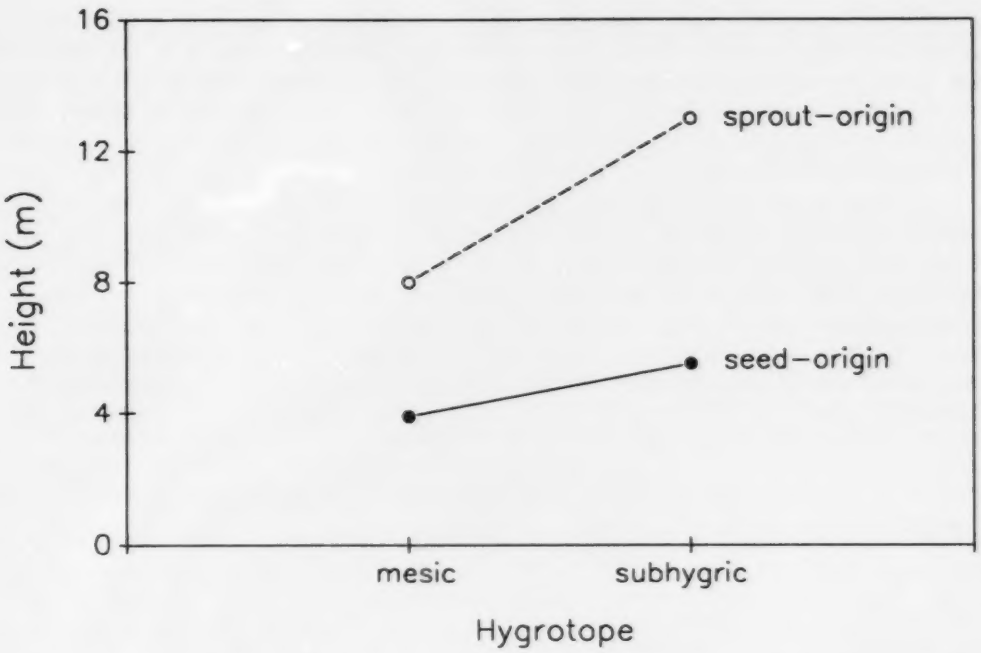


FIGURE 5-6. Height growth comparison of sprout origin and seed origin of 10-year cottonwood between mesic and subhygric sites.

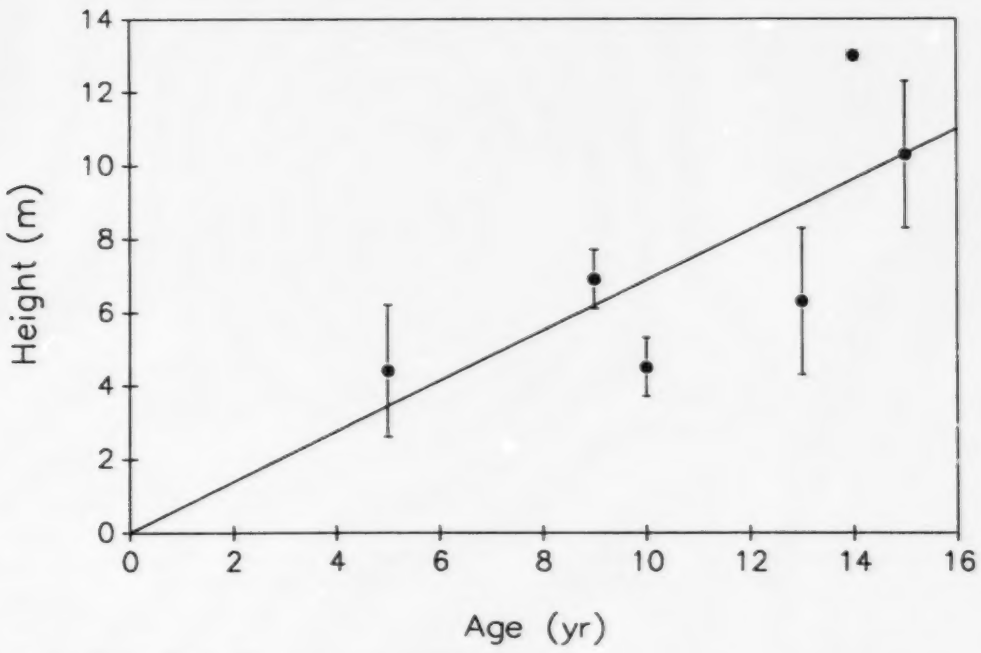


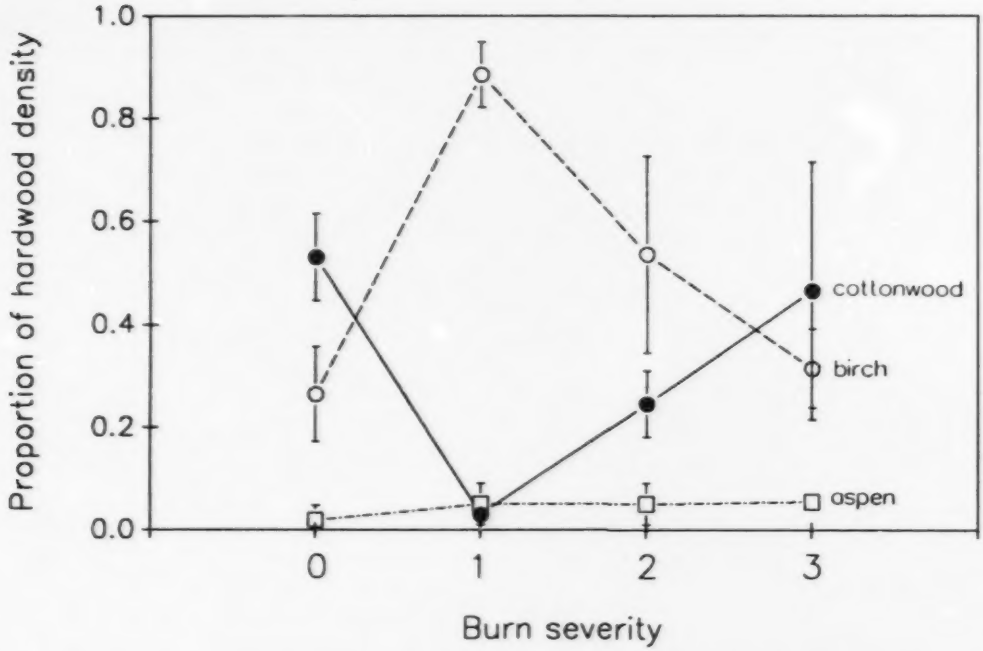
FIGURE 5-7. Aspen height growth in the ICH zone.

5.3 Effects of Site Preparation Treatments on Regeneration

Site preparation treatments were rated according to burn severity, as explained in Section 5.1. Severity was assessed on a linear scale from 0 to 3, where 0 was equivalent to no impact, 1 to light impact (slash and stumps lightly charred, minimal mineral soil exposure), and 3 to severe impact (slash and stumps hollowed out, over 50% mineral soil exposure). A burn severity of 2 (moderate impact) was intermediate between 1 and 3.

5.3.1 Species composition

Hardwood species composition on mesic sites varied according to the severity of burn (Figure 5-8). Birch and, to a lesser degree, cottonwood were consistently dominant; aspen was insignificant except in isolated clonal patches. Following no site preparation (severity 0), abundance of birch and cottonwood were similar. Dominance of one particular species over another depended on moisture availability. Following light or moderate impact burns, however, birch was clearly the most abundant. Birch stumps sprouted prolifically and seeds germinated readily on exposed mineral soil and mixed mineral/organic layers. Mechanical bunch-and-burn treatments that mixed soil and burned stumps resulted in the highest birch densities. Cottonwood stumps were severely damaged by fires of even light to moderate impact. In contrast to birch, cottonwood is **not** a fire-adapted species. Consequently, what cottonwood was present originated predominantly from seed. Following severe impact fire, hardwood density was severely reduced (see Section 5.3.2). Birch and cottonwood were of seedling origin and generally occurred in similar proportions.



Burn severity legend: 0 = none; 1 = light, stumps and logs partially burned; 2 = moderate, stumps and logs partially burned; 3 = severe, centres of stumps and logs burned out.

FIGURE 5-8. Hardwood species composition on mesic sites following site preparation treatments of different burn severity.

Regardless of burn severity, cottonwood consistently dominated skidroads, while birch dominated the remainder of the opening. Birch preferred mixed organic/mineral seedbeds, whereas cottonwood germinated readily and quickly out-competed birch on compacted and completely exposed mineral soil.

Conifer species composition on mesic sites also varied according to burn severity. New and advance western redcedar and western hemlock regeneration dominated sites receiving no site preparation treatment. They survived, albeit suppressed, under hardwood canopies. Sites that were not site prepared were not planted. As burn severity increased, the proportion of cedar and hemlock decreased and more light-demanding species (e.g., lodgepole pine, Douglas-fir) increased. The increase in those species was a result of planting and better light availability. Douglas-fir was by far the most commonly planted species, followed by spruce, lodgepole pine, and western larch.

5.3.2 Density and stocking

Hardwood stand density ranged between 5000 and 30 000 stems per hectare during the first 9 years following harvest. Microsite densities sometimes reached 60 000 stems per hectare. Density was greater on unburned and lightly burned than on moderately and severely burned sites (Figure 5-9). Dense stands of birch appeared to self-thin rapidly after 8–10 years. By the age of 15, density was reduced to approximately 5000 stems per hectare on unburned to lightly burned sites and 1300 stems per hectare on moderately to severely burned sites.

The highest hardwood densities occurred following light-impact burns (Figure 5-10). On mesic sites, species composition following light burns was about 90% birch (Figure 5-8). As burn severity increased, hardwood density declined dramatically and reached a minimum on severely burned sites. Severe burns presumably killed most hardwood roots and stumps, and reduced surface organic materials and availability of moisture and nutrients critical for germination. Both birch and cottonwood demand abundant moisture and nutrients (particularly nitrogen) for survival (Krajina *et al.* 1982), and most germinants could not meet their requirement on severely burned sites.

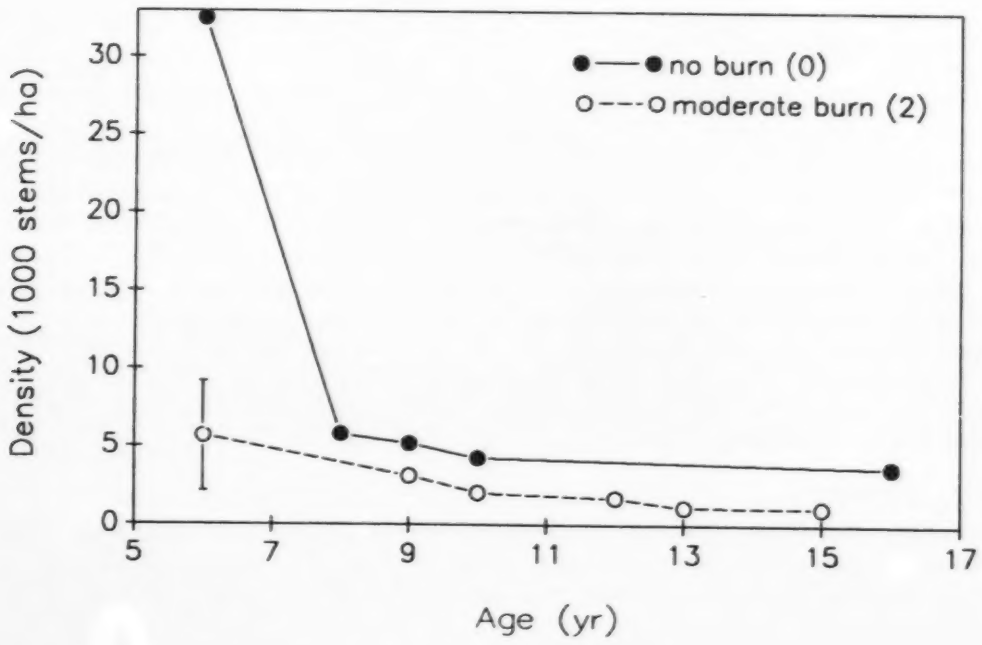
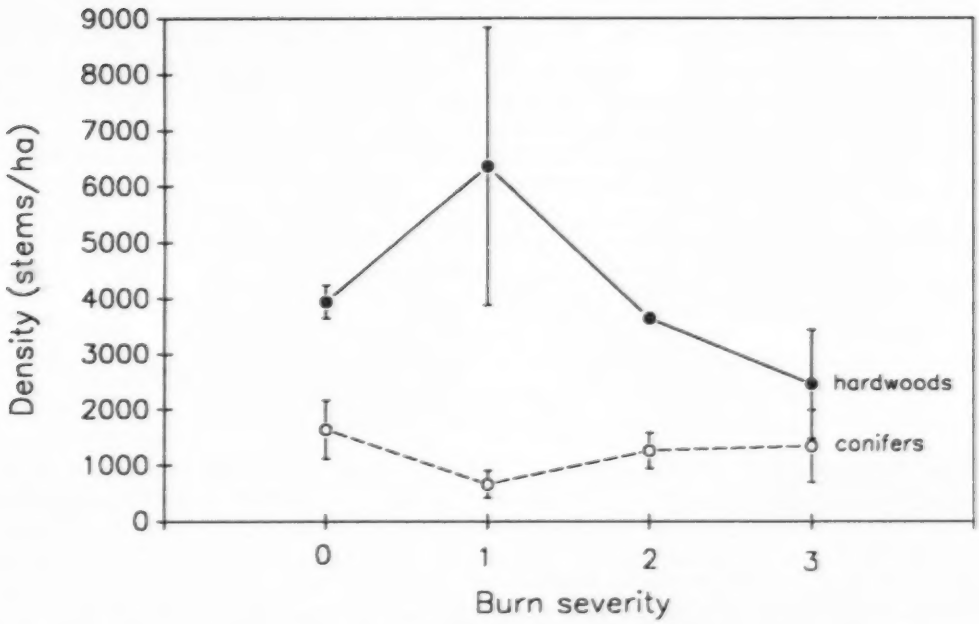


FIGURE 5-9. Changes in hardwood density over time.



Burn severity legend: 0 = none; 1 = light, stumps and logs partially burned; 2 = moderate, stumps and logs partially burned; 3 = severe, centres of stumps and logs burned out.

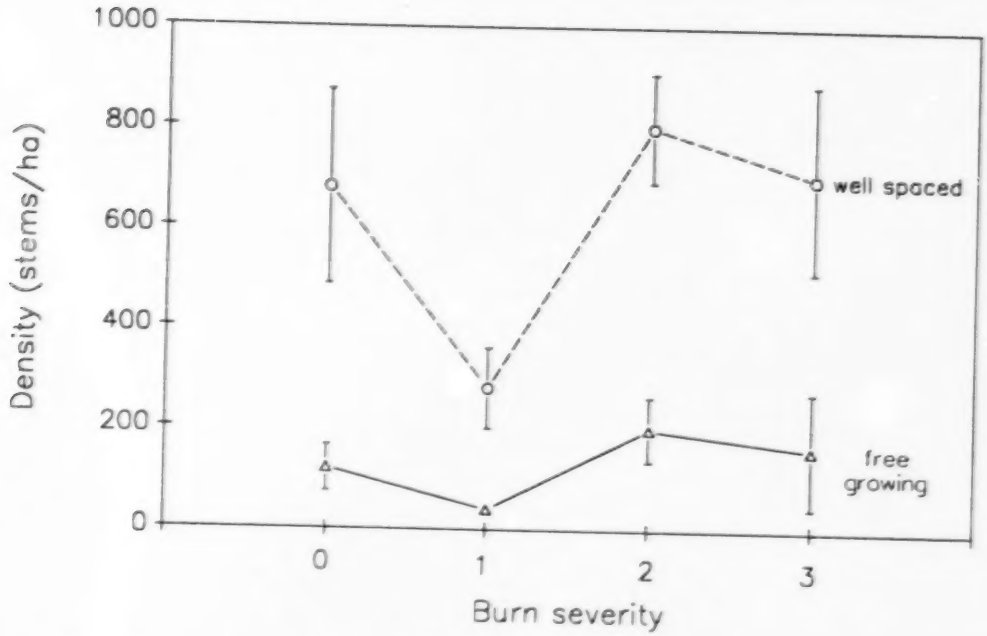
FIGURE 5-10. Density of hardwoods and conifers following site preparation treatments of different burn severity.

Conifer density on mesic sites generally increased with burn severity (Figure 5-10). Unburned sites boasted the highest conifer densities, although the stands were composed predominantly of advance cedar and hemlock. Average conifer density reached a minimum of 660 stems per hectare on lightly burned sites, which was below the minimum stocking standard of 700 stems per hectare (mesic). It reached a maximum of 1260–1340 stems per hectare on moderately to severely burned sites, which met the target stocking standard of 1200 stems per hectare (mesic) (Lloyd *et al.* 1990).

The average number of well-spaced conifers was below the minimum stocking standard (700 stems per hectare on mesic sites) on both unburned (650 stems per hectare) and lightly burned (300 stems per hectare) sites (Figure 5-11). It was above the minimum, however, on both moderately (810 stems per hectare) and severely (790 stems per hectare) burned sites. Although the number of free-growing stems peaked on moderately and severely burned sites (200 stems per hectare), it was well below the minimum requirement (700 stems per hectare).

5.3.3 Success

The success of management treatments for conifer, hardwood, and mixedwood production on each site was rated as not successful, moderately successful, or highly successful. The success ratings were based on species composition, stocking (total, well-spaced, and free-growing), and growth.



Burn severity legend: 0 = none; 1 = light, stumps and logs partially burned; 2 = moderate, stumps and logs partially burned; 3 = severe, centres of stumps and logs burned out.

FIGURE 5-11. Well-spaced and free-to-grow conifer stocking following site preparation treatments of different burn severity.

Except on unburned sites, the relative height of conifers to hardwoods generally increased with burn severity (Figure 5-12). On unburned sites, the average conifer height was relatively high because of the abundance of advance regeneration. On burned sites, the abundance and hence the competitive effects of neighbouring hardwoods decreased as burn severity increased from light to moderate impact. There was no difference in relative height, however, between moderately and severely burned sites.

Conifer production was most successful on sites that received moderate impact burns (Figure 5-13). Success declined slightly on severely burned sites, however, possibly as a result of the loss of organic matter. Very few of the unburned sites were highly successful for conifer production.

Hardwood production was most successful on lightly burned sites. It failed on severely burned sites.

Mixedwood production was most successful on moderately burned sites. On those sites, conifers met minimum stocking levels (700 stems per hectare) and hardwood density was low (about 1000 stems per hectare). Species composition was predominantly Douglas-fir and birch. A higher density of hardwoods could successfully be maintained if conifers able to tolerate lower light conditions (such as cedar or spruce) were planted.

Conifer success declined linearly as the delay between site preparation and planting increased (Figure 5-14). Whereas 80% success was met following a 1- or 2-year delay, only 50% success was met following a 5-year delay and 0% success following a 10-year delay. Mixedwood production was 60% successful following only a 1-year delay and 100% successful following a 5-year delay. Hardwoods clearly have the leading edge.

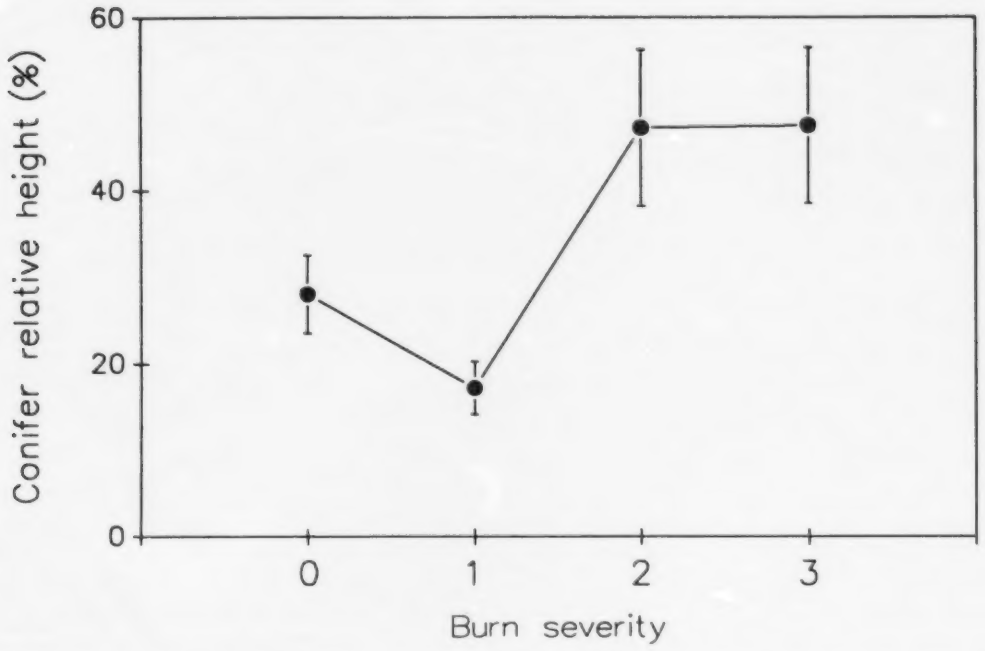


FIGURE 5-12. Height of conifers relative to birch following site preparation treatments of different burn severity.

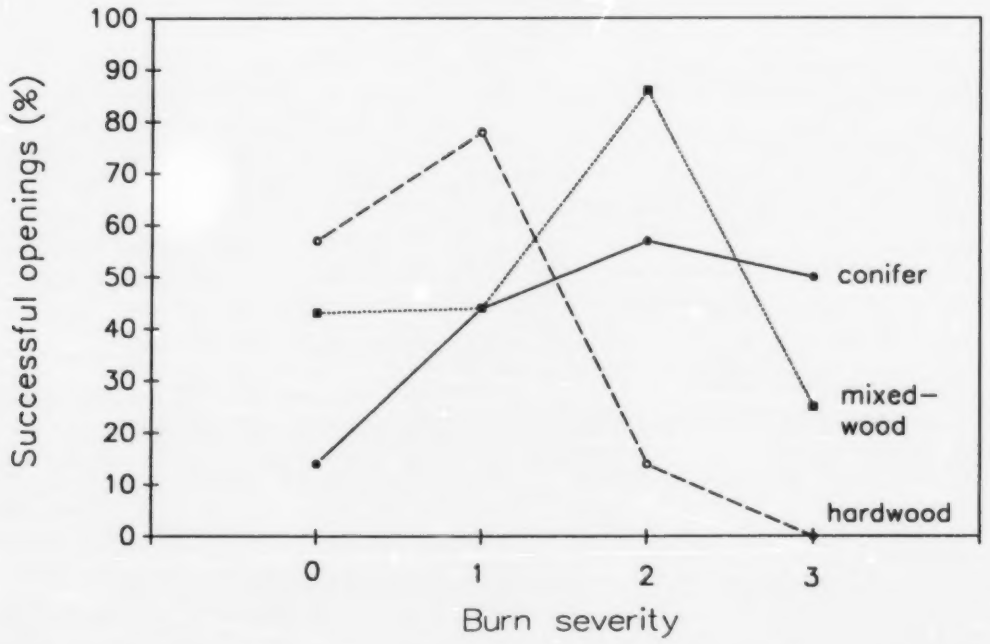


FIGURE 5-13. Percentage of openings rated as highly successful for conifer and hardwood production following site preparation treatments of different burn severity.

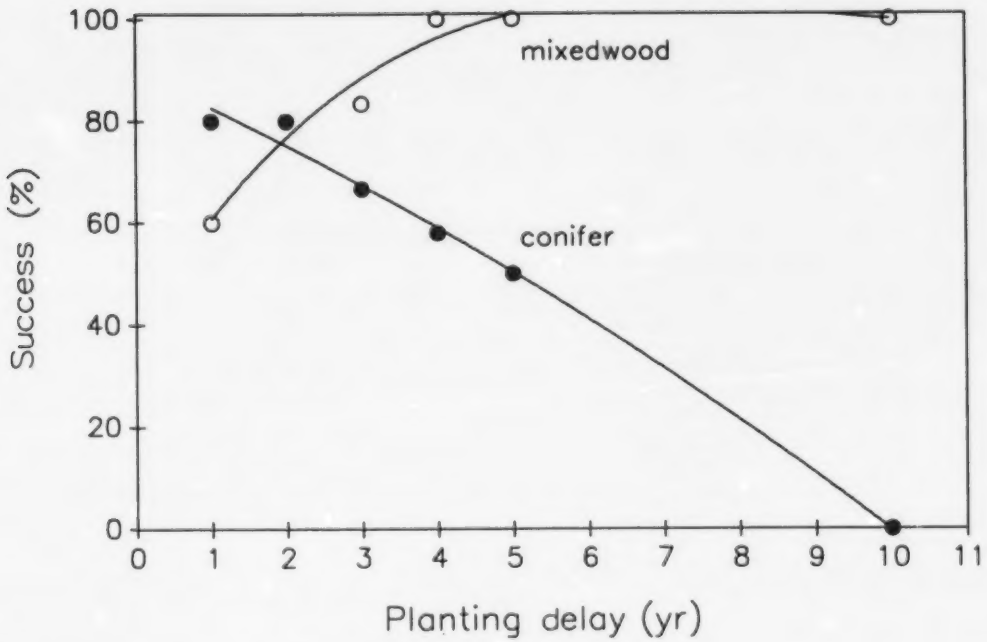


FIGURE 5-14. Mixedwood and conifer success following planting delays.

6 SILVICULTURE GUIDELINES FOR HARDWOOD AND MIXEDWOOD MANAGEMENT

Related problems and ecosystem-specific recommendations for conifer regeneration in the moist warm ICH subzones in the Kamloops Forest Region are reviewed by Mather[3] and Butt and Bancroft.[4] The purpose of this section is to recommend silviculture guidelines for hardwood and mixedwood production in the ICHmw2 and IDFmw2 variants. Hardwood production is best suited to subhygric sites. Although unmanaged stands contain a high proportion of cottonwood, birch can be favored through intermediate cuttings. Mixedwood production is suitable for mesic and subhygric sites, although the majority of unmanaged mixedwood stands are on mesic sites.

[3] Mather, 1988.
[4] Butt, G. and B. Bancroft. 1988. Analysis of regeneration problems in the Interior Cedar Hemlock zone in the Kamloops Forest Region. B.C. Min. For., Victoria, B.C. Unpubl. report.

TABLE 6-1. Recommended silviculture treatments for hardwood production in the ICHmw2 and ICHmw3 variants

Hygrotope	Silv. system	Site prep.	Regen. method	Species natural	Selection artif.	Stand tending	Rotation age (yr)	Other considerations
SM-SX	Low productivity; not recommended for hardwood management							
M	Clearcut	Mechanical or moderate burn	Natural (seed)	Birch	None	Thin[a]	40-50	-low understory brush hazard[b] -*Armillaria* root rot usually present
SHG	Clearcut	Mechanical or moderate to hot burn	Natural (seed)	Birch, cottonwood	None	Thin[a]	30-40	-moderate understory brush hazard[c] -*Armillaria* root rot usually present
HG	Riparian ecosystems; not recommended for hardwood management							

[a] Favour birch of seed origin. Cottonwood of seed origin may also be favoured on subhygric sites if heartrot is absent. Sprout-origin stems tend to have poor form and are more quickly infected with root and heart rot. Acceptable density profile is:

Mean dbh (cm)	Age (yr) Mesic	Age (yr) Subhygric	Density (stems/ha)
2.5	2-4	1-3	5500
5.0	5-7	4-6	4500
7.5	8-10	7-9	3000
10.0	12-14	10-12	2000
13.0	15+	13+	1000

[b] *Paxistima myrsinites, Epilobium angustifolium, Pteridium aquifolium, Rubus parviflorus.*
[c] *Rubus parviflorus, Epilobium angustifolium, Cornus sericea, Vaccinium* sp.

TABLE 6-2. Recommended silviculture treatments for hardwood production in the IDFmw2 variant

Hygrotope	Silv. system	Site prep.	Regen. method	Species natural	Selection artif.	Stand tending	Rotation age (yr)	Other considerations
SM-SX	Low productivity; not recommended for hardwood management							
M	Clearcut	Mechanical or moderate burn	Natural (seed)	Birch	None	Thin[a]	40-50	-low understory brush hazard[b] -*Armillaria* root rot usually present
SHG	Clearcut	Mechanical or moderate to hot burn	Natural (seed)	Birch, cottonwood	None	Thin[a]	30-50	-low-moderate understory brush hazard[c] -*Armillaria* root rot usually present
HG	Riparian ecosystems; not recommended for hardwood management							

[a] Favour birch of seed origin. Cottonwood of seed origin may also be favoured on subhygric sites if heartrot is absent. Sprout-origin stems tend to have poor form and are more quickly infected with root and heart rot. Acceptable density profile is:

Mean dbh (cm)	Age (yr) Mesic	Age (yr) Subhygric	Density (stems/ha)
2.5	3-5	2-4	5500
5.0	6-10	5-7	4500
7.5	11-15	8-10	3000
10.0	16-20	12-14	2000
13.0	20+	15+	1000

[b] *Paxistima myrsinites, Mahonia equifolium, Symphoricarpos albus, Epilobium angustifolium, Pteridium aquifolium, Rubus parviflorus.*
[c] *Rubus parviflorus, Epilobium angustifolium, Cornus sericea, Vaccinium* sp.

TABLE 6-3. Recommended silviculture treatments for mixedwood production

Hygrotope	Silv. system	Site prep.	Regen. method	Species natural	Selection artif.	Stand tending	Rotation age (yr)	Other considerations
SX	----------Low productivity; not recommended for hardwood management----------							
SM-M	Clearcut	Mechanical or moderate burn	Natural and plant	Birch Cw, Hw	Fd, Pl[a] Sx, Cw	Clean[b] Thin[c]	50 (Birch)[d] 80-100 (conifers)	-low understory brush hazard[e] -*Armillaria* root rot usually present
SHG	Clearcut	Mechanical or moderate to hot burn	Natural and plant	Birch, cottonwood Cw, Sx, Hw	Sc, Cw	Clean[b] Thin[c]	40 (hardwoods)[d] 70-80 (conifers)	-low-moderate understory brush hazard[f] -*Armillaria* root rot usually present
HG	----------Riparian ecosystems; not recommended for hardwood management----------							

[a] Plant conifers at recommended stocking. Shade-intolerant species (Fd, Pl) become spindly under dense shade of hardwoods; therefore, hardwood density should not exceed 1000 stems/ha during the regeneration period. Shade-tolerant species (Sx, Cw) are better adapted to growth under canopies; therefore, densities of 2000+ stems/ha are acceptable during the regeneration period.

[b] Ensure that conifers, particularly Douglas-fir or lodgepole pine, either are of equivalent height to neighbouring hardwoods or have a lot of growing space. Since hardwood growth rates far exceed those of conifers, however, intermediate cleanings around individual conifers will be necessary. More than one cleaning will likely be required if manual cutting is used, particularly in the case of shade-intolerant conifers. Cuttings should be done when root carbohydrate reserves are minimal (e.g., June–July) to reduce sprouting. At least two cleanings will be necessary if conifers are less than 1 m tall and perhaps only one if they are 1.5 m tall. During the first cleaning, neighbouring hardwoods should be removed within a 1-m radius of target conifers. The competition-free radius should be enlarged during successive cleanings. The final crop density (e.g., at 15 years) should not exceed 2000 stems/ha (e.g., 1300 conifers and 700 birch).

[c] Two alternatives are available after the initial cleaning. The first is to extend the competition-free radius as conifers take up more growing space. The second is to leave a nurse stand of well-spaced hardwoods to provide frost protection to conifers. Nurse stands are a viable alternative on frost-prone sites planted to shade-tolerant conifers.

[d] Hardwood rotations are considerably shorter than conifer rotations. Before hardwood harvest, locate skidroads in a manner that will minimize damage to conifers. Provide careful instructions to logging contractor.

[e] *Paxistima myrsinites, Epilobium angustifolium, Pteridium aquifolium, Rubus parviflorus* in the ICH zone. *Paxistima myrsinites, Mahonia aquifolium, Symphoricarpos albus, Rubus parviflorus, Epilobium angustifolium, Pteridium aquilinum* in the IDF zone.

[f] *Rubus parviflorus, Epilobium angustifolium, Cornus sericea, Vaccinium* spp. in the ICH zone. *Acer douglasii, Symphoricarpos albus, Streptopus roseus* in the IDF zone.

7 RECOMMENDATIONS

The information gathered in the field study and literature review, that will promote hardwood management for timber production, was used to develop recommendations for operational, research, and extension and demonstration activities. Three priorities were identified for operations, five for research and two for extension and demonstration. For each priority, the problem is stated and follow-up activities suggested.

Operational Priorities

The following three priorities were identified for operations:

1. Update Inventory

The present inventory information does not accurately define the hardwood resource.

Problems:

1. Age classes are over-estimated and height classes under-estimated.

2. Many areas mapped as not satisfactorily restocked (NSR) or as non-commercial brush (NCBr) now support hardwood stands of potential commercial value.

3. Mixedwood stands are frequently incorrectly identified. Information is needed on species composition, age class, height class, diameter distribution, growth and yield.

4. Decay, waste and breakage estimates are unreliable. Decay, in particular, is grossly under-estimated, particularly in ages over 50 years. For example, Ministry of Forests volume equations estimated 96% of total volume as merchantable in stands on mesic and subhygric sites that were older than 50 years. In addition, the proportion of merchantable volume increased from 47% in a 20- to 39-year age class to 90% in a 70 years and older age class. These estimates contradict published recovery factors of 17% for Grade 1 and 25% for Grade 2 lumber (Nielson 1980; Jasper Millworks and Woodland Resource Services 1987).

Suggested follow-up:

1. More accurate estimates of height:age relationships, diameter distribution, volume, and decay, waste and breakage in both hardwood and mixedwood stands.

2. Ground check of age and height classes typed on forest cover maps.

3. Re-definition and re-mapping of NSR and NCBr areas.

2. Improve growth projections

Growth curves for birch, cottonwood and aspen should be re-evaluated for the southern Interior. Growth projections are important for Allowable Annual Cut (AAC) calculations and rotation estimates.

Problems:

1. Site index curves published by the Ministry of Forests (1986b) do not accurately estimate juvenile height growth. For birch, estimates are optimistic for seed-origin stems and fairly accurate for sprout-origin stems. For cottonwood, estimates are fairly accurate for seed-origin stems, but they significantly under-rate sprout height growth. Insufficient data were collected to evaluate site index curves for aspen, but those aspen measured fell within the medium to good classification.

2. Site index curves do not accurately estimate height growth of maturing stands. For birch, height growth rates appear to decline by 20–30 years and mature height is attained by 50 years. Although some height growth likely occurs after 50 years, it is grossly over-estimated by the site index curves. For black cottonwood, height growth is under-estimated for the first 50 years and over-estimated beyond 50 years. As with birch, height growth is rapid during the first 20–30 years, after which it declines and is almost complete by age 50–60. For aspen, Peterson *et al.* (1989) identified two patterns of stand development in boreal forests near Prince George: some break up after 60 years; others remain intact and continue to add increment to at least age 90. Insufficient height/age data were collected to identify patterns in aspen stands in the ICH zone in the southern Interior.

3. Culmination of mean annual increment (MAI) will be over-estimated as a result of the inaccuracies of the site index curves. As derived from B.C. Ministry of Forests volume equations, culmination of MAI based on total volume (utilization of 30 cm stump height, 2 cm dib and 2 m log length) in the sampled stands on subhygric sites occurred between 50 and 70 years. However, the pathological rotation was only about 50 years. Peterson (1989) point out that calculating rotation age based on biomass rather than merchantable volume could shorten rotations by 10–15 years.

Suggested follow-up:

1. Refine site index curves for birch, black cottonwood and aspen.

2. Integrate growth and yield data collection with ecological site descriptions (see Lloyd *et al.* 1990).

3. Include hardwood and mixedwood management strategies in TSA plans

Problems:

The Ministry of Forests has traditionally concentrated on use of the coniferous resource. Hardwood and mixedwood management have not been included in TSA plans. The focus is changing rapidly, however, as commercial uses of hardwoods increase. Decisions will have to be made on which lands should be managed specifically for conifers, hardwoods or mixedwood. Reforestation guidelines will have to be developed for regeneration of hardwood and mixedwood stands.

Suggested follow-up:

1. Review existing tenures with regard to hardwood inventory and potential for producing hardwoods. Integrate hardwoods into AAC calculations and timber management policies.
2. Classify ecosystems suitable for hardwood and mixedwood management to assist in land use planning within TSAs.
3. Develop reforestation guidelines (stocking standards, stand tending practices, etc.) for prediction of regeneration response.

Research Priorities

The following five priorities were identified for future research on hardwood timber production.

1. Identify and classify ecosystems suitable for hardwood and mixedwood management.

Problem:

New interest in the use of hardwoods will require information on which areas should be managed specifically for conifers, hardwoods and mixedwood.

Suggested follow-up:

1. Develop a list of characteristics to classify sites as good or excellent for growth of paper birch, black cottonwood and mixedwood. These characteristics are readily available in the literature and from field observations.
2. Refine existing ecosystem classification for paper birch and black cottonwood types. The classification will aid in land use planning and regeneration strategies.

2. Develop hardwood stocking standards.

Stocking standards for the Kamloops Forest Region were developed according to acceptance of coniferous — but generally not deciduous — regeneration. For hardwood or mixedwood production objectives, new minimum and target stocking standards must be defined.

Problems:

1. Unlike for aspen, there is little information in the literature on acceptable stand densities for birch. In the northeastern United States, Solomon and Leak (1969) developed stocking guidelines to attain a minimum final density of ~1000 stems per hectare. To develop a stocked stand (1000 stems per hectare) with an average dbh of 13 cm, a maximum initial density of approximately 5500 stems per hectare (of average dbh 2.5 cm) is required. Sites between 1- and 5-years-old in the study area had an average dbh of 2.5 cm.

2. There is little information in the literature on acceptable densities, proportions and proximities of hardwoods and conifers in mixed stands. In Sweden, Andersson (1985) is investigating a mixed density of 2000 stems per hectare (1300 birch, 700 spruce). Point cleaning around individual conifers to a minimum radius of 1 m resulted in better conifer growth than did maintenance of a well-spaced nurse birch stand.

Suggested follow-up:

1. Trials investigating ranges in densities, proportions and proximities (spacing) of hardwoods and conifers should be initiated as soon as possible.
2. A survey of existing cutblocks should be undertaken to evaluate height (and leader) growth in relation to ecosystem, age, density and species proportions. Based on the survey, preliminary target and "free-growing" stocking standards could be developed.

3. Evaluate stand tending practices.

Methods, timing and stand suitability for stand tending must be investigated in pure and mixed birch stands.

Problems:

1. Birch appears to self-thin and self-prune readily. Thinning may be applied to concentrate growth on fewer larger stems; however, it may not be necessary to maximize fibre production. In addition, thinning results in basal sprouting and, as with pruning, may provide entry courts for decay-causing fungi.
2. The final cutting of hardwoods must be timed when hardwoods will bring a commercial return and when growth response of released conifers is greatest.
3. In mixedwood stands, methods on how to remove hardwoods without damaging conifers is of concern.

Suggested follow-up:

1. Thinning trials should be established in existing birch stands (that are old enough that dominance has been established) to see whether tree size and yield are increased. Trials should be established where they can complement growth and yield studies. Manual and chemical thinning methods should be compared. Season of cutting, and residual densities which result in minimum sprouting, should be investigated.
2. Sites that have the best potential for lumber or veneer production should be identified on an ecosystem basis. Priority should be given to those sites for thinning trials.
3. Trials should be initiated to identify the age of release which results in the greatest conifer growth response.
4. Methods of overstory removal that minimize mechanical damage to conifers in mixedwood stands should be investigated. Studies of the removal of overstory aspen from spruce stands provide some guidelines on logging methods (Froning 1980).

4. Evaluate the effects of pests on hardwood stands.

Pests include insects, pathogens, animals and neighbouring non-crop vegetation.

Problems:

1. Many insects attack birch at all stages of growth and over all parts of the tree. They include sap-suckers, defoliators, bark beetles, ambrosia beetles, and borers.
2. Many diseases affect birch, including trunk rots, sap rots and heart rots. Birch is susceptible to damage from the same rots (*Armillaria*) that cause significant mortality to conifers in the ICH zone.

3. Birch is an important food of white-tailed deer, moose, squirrels, porcupines and snowshoe hares.
4. Shrub and herb species commonly associated with birch in the ICH zone are potentially strong competitors and include fireweed, thimbleberry and bracken.

Suggested follow-up:

1. Root rot management is a priority in the ICH zone. Studies should be initiated to determine the effects of root rot on birch performance and, conversely, the effects of birch on the persistence and spread of root rot.
2. Small scale competition studies should be initiated to study the effects of neighbouring vegetation on the growth of birch.

5. Evaluate the effects of hardwoods on long-term ecosystem productivity.

Hardwoods have been shown to have a positive effect on soil development (Frivold 1985; Richardson *et al.* 1985; Torzewski and Lopinska 1985; Foster and King 1986; Hendrickson 1987). However, there are no long-term studies in British Columbia that investigate the influence of birch on ecosystem productivity.

Problems:

1. A common practice in the southern Interior is to reduce or remove hardwoods to achieve "free-growing" conifers. The effects of such practices on the nutrient capital of forest soils and the resilience of stands to catastrophic events (e.g., insect epidemics, pathogens) are unknown.
2. Hardwoods are usually harvested by whole-tree skidding, leaving foliage and other "debris" at the landing. The contribution of branches, bark and foliage to the nutrient capital of the site is likely significant. Nutrient losses are of particular concern if hardwoods are managed on a short rotation (e.g., less than 60 years).

Suggested follow-up:

1. Long-term ecosystem productivity research should be initiated in conjunction with managed stand growth and yield studies as soon as possible. Effects of management practices on stand dynamics and species diversity should be important components of the program.
2. The contribution of branches, bark and foliage to site biomass and nutrient capital should be identified so that the effects of whole-tree skidding on long-term productivity may be evaluated.

Extension and Demonstration Priorities

Problem:

Extension, education and demonstration are needed to increase awareness among foresters, woodlot managers, farmers, ranchers and the general public about the opportunities and problems associated with hardwood use.

Suggested follow-up:

1. Establish demonstration areas over a range of stand and site conditions. Research trials will be used as demonstration sites.
2. Support an extension program through the following activities:
   a. Prepare a handbook that describes management of hardwoods on an ecosystem unit basis. Information on harvesting, site preparation, regeneration, stand tending and decay should be included.
   b. Provide a workshop to private, industry and government sectors which exclusively deals with hardwood management issues.
   c. Prepare training courses and extension leaflets for identifying and managing sites suitable for hardwood production.

APPENDIX 1. Literature review of paper birch

1.1 Distribution

Paper birch occurs at low to mid-elevations in the southern Interior. It is common in the Interior Cedar Hemlock (ICH), Interior Douglas-fir (IDF), Montane Spruce (MS) and Sub-boreal Spruce (SBS) biogeoclimatic zones. It is uncommon in the Ponderosa Pine (PP) and Bunchgrass (BG) zones and absent from the Engelmann Spruce-Subalpine Fir (ESSF) and Alpine Tundra (AT) zones. It is most abundant and reaches its greatest productivity in the ICH zone, which occupies the warm, moist valleys of the southern Interior, but it also grows well in transitional climates, such as in the Coast/Interior ecotone and between the dry and wet belts in the southern Interior.

1.2 Habitat

Paper birch is adapted to a wide range of climates from humid to boreal, but, it does not tolerate the perhumid climate of the coast or the extremely heavy snow loads of some areas (Fowells 1965). It grows on a wide variety of soil moisture regimes (subxeric to subhygric) (Angove and Bancroft 1983) and textures (gravelly sands to organics), but best growth occurs on moist, well-drained, sandy or silty soils. Although paper birch tolerates poorly drained soils (Krajina *et al.* 1982), its growth is depressed on very wet sites (Tang and Kozlowski 1982; Norby and Kozlowski 1983).

Paper birch is also adapted to a wide range of nutritional conditions (Post *et al.* 1969), although it prefers medium to rich sites. Its nutritional requirements are moderate (for nitrogen and sulphur) to high (for calcium and magnesium) and it tolerates acidic to calcareous soils (Fowells 1965; Watson *et al.* 1980; Krajina *et al.* 1982).

The species is shade intolerant (Hosie 1973; Krajina *et al.* 1982) and hence usually only lasts one generation in natural succession (Fowells 1965). It is a common component of climax forests, however, where gaps have been created by disturbances such as blowdown (Ohmann *et al.* 1990; Hibbs 1982; Perkins *et al.* 1988; Vogelmann *et al.* 1988) or root rot.

As well, it is very frost resistant (Krajina *et al.* 1982) and often starts growing in the spring while temperatures are still below freezing (Fowells 1965). It is tolerant of high summer temperatures, provided sufficient moisture is available.

1.3 Reproduction

Reproduction is mostly from seed, although, stumps and root collars sprout vigorously following cutting or fire (Fowells 1965; Hyvarinen 1968; Klinka and Scagel 1984). Paper birch bears seed by age 15 and reaches its optimum production between ages 40 and 70. Seed is produced annually and good crops occur every 2–4 years. Solitary birches produce more (10 times) seed than trees in stands; for example, a solitary *Betula verrucosa* in Sweden produced 6.5 MM seeds. Seeds remain viable for up to 2 years.

The seed (winged nutlets) are dispersed by wind and water and, although they are easily transported long distances (200+ m), almost all fall within two to three tree lengths (100 m) of the parent tree. The majority fall within 25 m. However, birch trees isolated in equally tall spruce stands spread only about 25% of their seed within 40 m and the rest further afield. Consequently, those birches standing several metres from clearcut edges can contribute to seed-fall within the clearcut (Fries 1985).

Seed is dispersed in the fall and early winter (August to January) and germination normally occurs the following spring. Germination occurs immediately after threshold temperatures are reached and after the snow melts (Zasada *et al.* 1983). It is best in moist, mixed mineral/organic soil and in the shade (Marquis 1966), although it does occur readily in clearcuts.

Vegetative sprouts originate from adventitious buds in the root collar following a disturbance (Hagman 1985). Most of the buds are located just below ground level, so stump height should not be correlated with

sprouting frequency (Johansson 1985). Denisov and Maiorov (1987), however, found that more lateral sprouts grew on tall (1–1.5 m) compared with short (0.1–0.5 m) stumps. The greater frequency of lateral sprouts retarded the growth of the more vigorous root collar sprouts. Sprouting vigour decreases with age and appears to be reduced when stems are cut in May–June, at the time root carbohydrate reserves are minimal (Andersson 1985; Johansson 1985; Denisov and Maiorov 1987). Light and high temperatures stimulate the growth of sprouts, so growth is faster following clearcutting than thinning (Johansson 1985).

1.4 Growth and Development

Paper birch characteristically invades burned areas and rapidly forms even-aged pure stands from seed or stump sprouts. Juvenile growth rates are moderate relative to that in other hardwoods such as black cottonwood. In the ICH zone, first-year seedling growth can reach 40 cm on favourable sites, but averages only about 10 cm. Grant and Thompson (1975) report heights of 32 cm after 3 years and 381 cm after 6 years. Growth of sprouts is considerably more rapid than that of seedlings; it ranges between 0.5 and 2 m/year in the ICH zone. Young stands are usually very dense, and thus trees close crown at an early age and self-thin rapidly.

Polymorphic height growth patterns are common among trees growing on sites of different quality (Carmean 1985). That is, birch on good sites exhibits rapid early height growth followed by a marked slowing of growth after 50 years. Birch on poor sites, in contrast, has much slower height growth that follows an almost linear pattern. On subhygric sites in the ICH zone, mature birch trees reach a height of 30–40 m and a dbh of 50–100 cm. The amount and duration of radial stem growth is directly related to leaf volume (Braekke and Kozlowski 1975).

Many birch trees are multi-stemmed (2–15 stems per individual) with sweeping boles. Multiple stems may arise from either early disturbance to a seedling or from disturbance to the parent tree which subsequently formed basal sprouts.

Maturity of seedling-origin birch stems is reached in 60–70 years and of sprout-origin stems in 50–60 years, at which time height growth almost ceases and susceptibility to pathogens increases (Ohmann *et al.* 1990).

Root systems are deep and penetrating (Fowells 1965; Hosie 1973).

1.5 Growth and Yield

Growth and yield of paper birch is related to site quality. Poor sites include ridges and steep colluvial slopes. Good sites include well-drained flats and rolling terrain.

Site Index

A site index equation for paper birch in British Columbia, at a reference age of 100 years, was developed by the B.C. Ministry of Forests based on a sample of 1114 trees. The equation is a poor model of birch height growth, since it represents a monomorphic curve (i.e., the same shape for all site qualities). The equation is:

$$\text{Site Index}_{(100)} = \text{Height} / (b_1(1-e^{b_2 * Age})^{b_3})$$

where: $b_1 = 1.1580$, $b_2 = -0.0175$ and $b_3 = 0.7687$.

The conversion factor for $SI_{(50)}$ is 0.76501288. Compared with birch height growth patterns reported in the literature, this site index equation clearly under-estimates height growth during the first 50 years and over-estimates it between 50 and 100 years.

Site index curves have been developed for paper birch in British Columbia (B.C. Ministry of Forests 1986a), Alaska (Gregory and Haack 1965) and the eastern United States (Solomon and Leak 1969). All curves are monomorphic across the range of site quality reported. In British Columbia, site index (50 years) on a good site ranges from 25 to 30 m, on a medium site from 16 to 25 m, and on a poor site from 9 to 16 m. The site index curves for the northeastern United States are similar to those in British Columbia: good sites have a site index of 27 m and poor sites 12 m. In Alaska, potential yield is considerably lower, with site indexes ranging from a high of 20 m to a low of 10 m.

Stocking

Solomon and Leak (1969) determined the number of birch trees at a given initial diameter required to produce one tree at a future diameter of 13 cm for sapling stands in the eastern United States (Table A-1). In a stocking survey using 10-m^2 plots ($r = 1.78$ m), each plot should contain at least the average, and preferably the high, number of stems reported in Table A-1 to produce one good stem when the stand reaches a mean dbh of 13 cm. Their stocking guide for older stands assumes that a minimum of 956 well-spaced stems per hectare are required to use the site fully when the stand reaches a mean dbh of 13 cm.

TABLE A-1. Average and high confidence ($p < 0.15$) numbers of birch stems required to produce one stem of 13 cm dbh (from Solomon and Leak 1969)

Initial mean dbh (cm)	Average no.	High no.	Average no./ha	High no./ha
2.5	3.7	6	3537	5736
5.1	2.7	5	2581	4780
7.6	1.9	3	1816	2868
10.2	1.4	2	1338	1912

Stocking guides are also essential for applying thinnings to even-aged stands of paper birch. Solomon and Leak (1969) developed a thinning guide for the main canopy of pole and sawtimber-sized (13+ cm dbh) stands in the northeastern U.S. (Figure A-1). In the guide, the A line represents an unmanaged stand; the B line represents minimum stocking for full site utilization and adequate growth without competition; and the C line represents the level where 10 years of growth on an average site will raise the standard to the B stocking line. Stands above A are overstocked, stands between A and B are adequately stocked, and those below C are understocked. Thinning should be considered when stocking is more than half-way between A and B. Stocking after thinning should be near B.

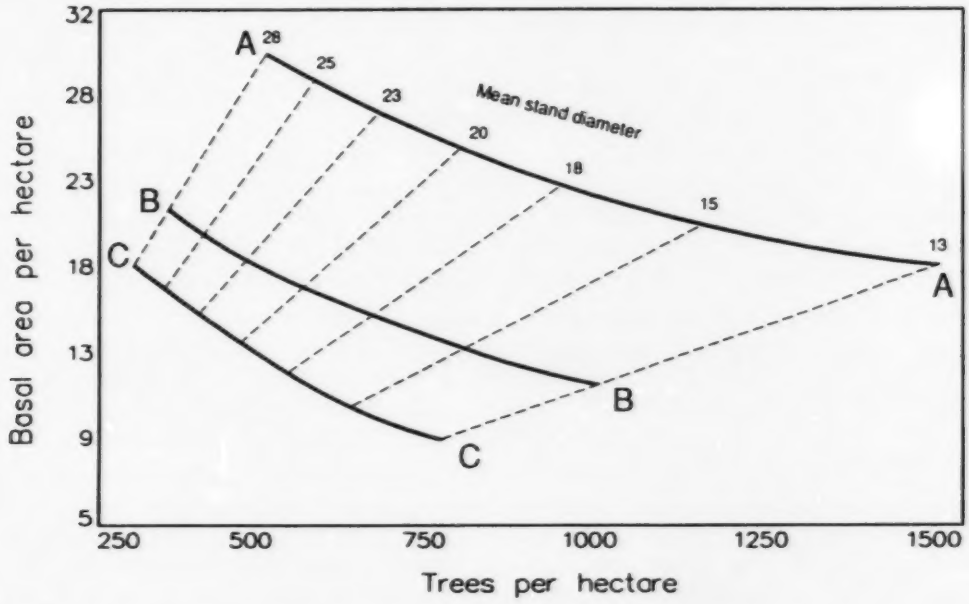


FIGURE A-1. Stocking guide for pure even-aged paper birch stands, showing basal area per hectare, numbers of trees per hectare, and mean dbh for trees in the main canopy (from Solomon and Leak 1969).

After moderate (25–30% of the basal area removed) and heavy (40% of the basal area removed) thinning in 25-year-old even-aged birch stands in the northeastern U.S., Solomon and Leak (1969) found that birch diameter growth increased by nearly 30%. There was very little difference in response, however, between the two thinning regimes. In older stands (>65 years), thinning response was considerably less. Ohmann *et al.* (1990) and Solomon and Leak (1969) concluded that intermediate thinnings in birch stands should substantially increase yields, improve quality, and shorten rotations by 10–20 years.

Yield

Volume equations for British Columbia's conifer and hardwood species were developed by the B.C. Ministry of Forests (1976) and compiled in a FORTRAN program by Kozak (1989). The equations are based on forestry inventory zone (FIZ), maturity class, height and diameter at breast height.

The volume/age equations (and curves) developed by the B.C. Ministry of Forests are based on the Chapman-Richards non-linear growth model:

$$\text{Volume}=b_1(1-e^{b_2 * \text{Age}})^{b_3}$$

where b_1, b_2, and b_3 are regression coefficients. Plot data from variously aged natural stands were stratified into 12 FIZ's, 17 Growth Type Groups, and 4 Site Classes (Good, Medium, Poor and Low). Regression coefficients were derived for each stratum (FIZ, growth type group, site class) for net merchantable volume (less decay) at close utilization standard (30 cm stump height, 10 cm top dib) and 12.5+ cm dbh. For detailed planning and stand prescriptions, the Chapman-Richards growth model was modified by the addition of site index, average basal area (m^2) per hectare, and average stand diameter. For inventories using aerial photographs over extensive areas, site index, average stand basal area, and stand diameter are derived from estimates of crown closure, stand height and stand age.

The current yield estimation by the B.C. Ministry of Forests, however, does not meet the needs of the re-inventory program because it is not species specific and it uses broad growth type and stocking classes. A new yield estimation system is now being developed, which responds to the current level of forest classification in British Columbia. The growth and yield model will include the following parameters: species (± 1%), age (± 1 year), height (± 0.1 m), crown closure (± 10%), pure species coefficients, pro-rated species percent for mixed stands, mixed stand adjustments, and growth projection calibration (B.C. Ministry of Forests 1989). Because the new system is species specific and sensitive to species composition in mixed stands, it will more accurately estimate yield and project growth in mixedwood stands.

1.6 Succession

Natural forest fires have largely shaped the succession of boreal forests (Carmean 1985). Fire seral stands are influenced by the size of the fire, the physiography of the landscape, and species composition. Large, severe fires expose mineral soil and create open site conditions. The sprouts and suckers of birch, cottonwood and aspen may be destroyed. Depending on the nearby seed source, however, pure even-aged stands of either conifers or hardwoods quickly establish. The burned forest that gives rise to birch stands may have contained only scattered birch, but because of the relatively low flammability of birch compared with conifers, birch individuals frequently survive where conifers do not. The open site conditions created by the fire are ideal for birch seedling establishment and sprouting from surviving roots. Dense even-aged stands can quickly develop. Since little ingress of birch seedlings occurs once these stands are established, birch stands are characterized by a lack of stems in the younger age classes (Foster and King 1986).

The developing birch stand generally undergoes one of three changes. First, in the absence of disturbance, shade-tolerant conifers such as western redcedar and western hemlock might increase in abundance. Birch is a short-lived intolerant species and stands start to deteriorate by about 70 years of age. As the stand opens, conifer dominance increases until a climax cedar-hemlock stand develops. Second, disease might cause mortality in conifer stands and gaps might develop which are invaded by birch. Third, a severe fire or the use of herbicides following timber harvesting might consume paper birch and result in local elimination of the species (Carmean 1985; Foster and King 1986).

1.7 Development of Mixed Birch and Conifer Stands

Paper birch is an aggressive pioneer (Watson and Parker 1980). Where birch seeds-in densely, it competes strongly with young conifers for resources. Mortality of white spruce, for example, is increased under dense birch stands (Gregory 1966; Arlidge 1967). In Scandinavia, fast growing silver birch (*Betula pendula*) has a negative effect on the diameter and height growth of pine, spruce and even birch itself in mixed stands (Andersson 1985; Braathe 1985; Mielikainen 1985). In the ICH zone in the southern interior of British Columbia, height and diameter growth of Douglas-fir decreases as paper birch density increases.[5] Light-demanding species such as Douglas-fir and lodgepole pine suffer greater photosynthetic losses under the shade of birch than do the more shade-tolerant species such as spruce, cedar and hemlock. In Scandinavia, shade-tolerant spruce regenerates easily and is actually planted under birch for frost protection (Mielikainen 1985).

The early height growth of birch, particularly sprouts (initially 1–2 m/yr), is by far superior to that of conifers (initially 5–25 cm/yr). The difference in height growth precludes the possibility of growing mixed stands without intermediate cuttings. The conifers need a few years of advance growth or a lot of growing space to survive. In Scandinavia, Mielikainen (1985) recommends that conifers be given an initial height advantage of 1 m on medium sites and 1.5 m on good sites (7–8 years growth) over birch.

Nurse stands of birch offer frost protection to conifers, inhibit the growth of birch sprouts from cut stumps, and improve conifer quality by having a pruning effect on branches. In Scandinavia, a minimum of 1500, five-metre tall silver birch per hectare are required to sufficiently provide frost protection to 500 spruce per hectare and inhibit birch sprouting. Birch density can be managed so that conifers maintain a similar height increment as the birch. Nurse stands, however, will depress diameter increment and may damage conifer leaders through whipping (Andersson 1985).

The density of birch and conifers must be carefully managed when they are grown together in mixture. Pure birch stands must be less dense than pure conifer stands because birch individuals require more growing space. Mixed stands can be grown more densely than pure birch stands because individual birch trees "perceive" surrounding conifers as being less competitive than surrounding birch (Mielikainen 1985). This may be attributed to the two species' ability to occupy separate root and crown growing spaces (Frivold 1985; Mielikainen 1985). In addition, birch individuals perceive pines to be more competitive than spruce, probably because of pine's early rapid growth rate (Agestam 1985). The effect of the mixture on individual conifers is almost always negative, however, because conifers perceive surrounding birch as being more competitive than surrounding conifers.

Jensen (1983) recognized an "effect of species mixture" — that is, the mixture itself appears to influence the growth of individual trees (Frivold 1985). On medium to good sites in Scandinavia, for example, the rapid early growth of silver birch increases the total volume growth of young mixed stands of silver birch and conifers (Scots pine or Norway spruce) compared to that of pure stands (Mielikainen 1985; Andersson 1985). Mielikainen (1985) found that the greatest growth occurred when silver birch comprised 30–50% of the stand. Increasing the density of birch beyond the critical density resulted in a decrease in total volume growth. At the optimal birch density, the production of sawtimber increased by 9% on good sites and decreased by 6% on poor sites. In another study, 50% of birch resulted in pH increments of 0.2–0.3 in humus layers (Liljelund 1988).

Unlike in young stands, the presence of birch in older (50+ years) stands results in a loss of volume growth, particularly in stands of intolerant conifers such as pine. Consequently, intermediate cuttings of birch are necessary in pine stands to ensure the production of large-sized pine tree. On the other hand, a silver birch mixture can be maintained in spruce stands throughout the rotation without the loss of large-sized trees (Mielikainen 1985).

On poor sites, conifers generally are of better quality and have greater yields than birch (Carmean 1985; Braastad 1985). Furthermore, poor sites have less vigorous birch regeneration and thus are easier to convert to conifers. On good sites, in contrast, hardwood regeneration is very vigorous. In dense birch stands, competition with conifers is severe and conversion to conifers is risky and expensive. Good sites are also capable of quickly

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[5] Simard, S. 1990. Competition between paper birch and planted Douglas-fir in the southern interior of British Columbia. B.C. Min. For. and For. Can., Victoria, B.C. FRDA 3.67. Unpubl. report.

producing high yields of quality saw and veneer logs. Hence, for poor sites the goal should be to maintain conifers, and for good sites, either pure birch (Carmean 1985) or mixtures of birch and conifers (Andersson 1985; Mielikainen 1985).

1.8 Influence of Birch on Ecosystem Productivity

Many studies indicate that conifer monocultures lead to acidification, podzolization, and degradation of forest soils, and that deciduous trees have a favourable effect on soil development and productivity (Frivold 1985; Richardson *et al.* 1985). Birch may affect site productivity through the relatively high concentration of nutrients in the leaves, wood and bark (Torzewski and Lopinska 1985; Hendrickson 1987; Hendrickson *et al.* 1987), rapid litter turnover, and deep rooting habit (Foster and King 1986; Hauessler and Coates 1986). Birch leaves, branches and stems also have a strong modifying effect on the chemistry of water moving through the overstory (Price and Watters 1988). Shade-tolerant understory species, such as cedar, hemlock and spruce, may depend to a limited extent on nutrient enrichment from this canopy throughfall.

Decomposition of silver birch leaves is much faster than that of Scots pine (Johansson 1986) and Norway spruce needles in Sweden (Johansson 1985). Litterfall of planted birch has resulted in the formation of mull humus forms with a high pH (Troedsson 1985; Liljelund 1988). As the density of birch increased, the pH in the litter and A horizons increased. Due to the over-riding effect of climatic conditions, however, mulls with a high pH do not always form under birch stands (Troedsson 1985).

Total nitrogen, birch seedling biomass production, and nitrogen uptake were compared among forest floors taken from paper birch, aspen, balsam poplar, and spruce stands in interior Alaska. Extractable N was 15 times greater and seedling yield and N uptake 5–6 times greater with the paper birch than with the white spruce floor. Values were intermediate for aspen and balsam poplar (Van Cleve *et al.* 1986).

Biological scientists commonly believe that ecosystem diversity is conducive to ecosystem stability. Mixed stands of coniferous and deciduous species are more resistant to insect attacks, pathogen infections, blowdown, and the acidifying effects of pollution. Furthermore, mixed stands enhance wildlife use and aesthetic qualities (Frivold 1985).

1.9 Pests

Many insect species attack paper birch at all stages of growth and over all parts of the tree. Birch seedlings may be destroyed by root-feeding insects (e.g., white grubs, weevil larvae and wireworms) and above-ground feeders (e.g., cutworms). However, damage is rare because of the small numbers of insects under forested conditions and their limited mobility during the larval feeding stages.

Birch saplings and older trees are not ordinarily damaged seriously by root-feeding insects. However, the canopy foliage is host to both sap-sucking and chewing insects. Among the sap-suckers (Hemiptera and Homoptera), there are a number of species of birch aphids, lace bugs (Tingidae), mirid plant bugs (Miridae), and leafhoppers (genera *Oncopsis* and *Erythroneura*). Among the chewing insects, the birch skeletonizer (*Bucculatrix canadensella*) periodically reaches epidemic numbers and causes complete defoliation. There are at least two leaf-mining sawflies, *Heterarthrus memoratus* and *Profenusa thomsoni*, which show a preference to paper birch. The former may kill top branches and cause a reduction in annual growth and wood quality. The defoliators devour all or most of the leaf. The most common defoliators are the forest tent caterpillar (*Malacosoma disstria*), the gypsy moth (*Lymantria dispar*), and the saddled prominent (*Heterocampa guttivita*). Defoliation not only reduces annual growth, it also weakens trees so that they are susceptible to secondary attacks by bark beetles, ambrosia beetles and various borers, which ultimately kill the tree. The bronze birch borer (*Agrilus anxius*) is the most important borer affecting paper birch, attacking the crown and progressing down into the bole. The larvae feed on the inner bark and may eventually girdle the tree (Allen 1986).

Of the many diseases that affect paper birch, *Phellinus* spp., *Fomes igniarius*, and *F. applanatus* trunk rots are most important in older stands (Ohmann *et al.* 1990). *Armillaria* is also an important root rot in the southern interior of British Columbia (H. Merler, pers. comm., 1990). Most other diseases are associated with mechanically caused wounds to the stem. Every wound results in a column of discoloured wood, which may become decayed (Shortle 1986). Wounds are infected by fungi and bacteria that attack the phloem and sapwood.

Common sap rots include *Polyporus hirsutus*, *P. versicolor*, and *Chrondrostereum purpureum*. *Poria* spp. cause cankers in older birch stands (Ohmann *et al.* 1990). Birch also falls victim to the leaf rust, *Melampsoridium betulinum* (Foster and Wallis 1974).

Dieback, a progressive dying of twigs and branches from the treetop downward, is a serious, chronic problem of paper birch (Allen 1986). It results in reduced vigour and growth and may ultimately lead to death (Fowells 1965; Hyvarinen 1968). The cause of birch dieback has not been determined, but age, drought, shallow rooting, defoliation, and the foliage disease, *Sirococcus*, may be contributing factors (Pormerleau and Lortie 1962; Hyvarinen 1968; Allen 1986; Hopkins and Funk 1986). Trees suffering from dieback are thereafter susceptible to lethal secondary agents, particularly the bronze birch borer.

Birch is an important food for white-tailed deer, moose, squirrels, porcupines and snowshoe hares (Hyvarinen 1968; Jordan and Rushmore 1969; Banfield 1974; Singleton 1976; Wolff 1978; Chapman and Feldhamer 1983; Miquelle 1983; Maillette 1987; Schwartz *et al.* 1988). It is a moderately important winter browse for mule deer, Rocky Mountain elk, caribou and mountain goats.[6]

1.10 Wood Quality and Properties

Paper birch wood is of high quality and suitable for many uses (Sachsse 1989). It has a fine, even texture and uniform grain. The wood is diffuse porous. The widest pores are wider than the widest rays, which are not visible to the naked eye. As in most hardwoods, the fibre tracheids are short (Hyvarinen 1968).

The sapwood of paper birch is white and 5–10 cm thick in mature trees. It frequently makes up nearly the whole stem in rapidly grown saplings. The heartwood is light reddish brown. The wood around the pith is usually discoloured and contains small checks, shakes and pin knots. Growth rings are hard to see without a hand lens.

The wood is moderately dense (specific gravity is 0.57 and 0.51 g/cm^3 of dry and wet wood, respectively) (Kennedy 1965) and moderately hard (Viereck and Little 1972). Physical and mechanical properties are intermediate compared with other North American woods. Bending strength, stiffness and weakness in compression are moderate (Hyvarinen 1968). Flexural strength is about the same (5700 psi) as for jack pine, but not as high as for balsam fir (8000 psi) or spruce (6000 psi) (Baldwin and Yan 1968).

An important wood quality consideration is the effect of fast growth on density. There appears to be an inverse relationship between growth rate and density. Hardness, compression and bending strength decrease with wider ring widths (Kennedy 1968).

The average green moisture content of paper birch is 72% (aspen and black cottonwood are 90% and 175%, respectively). The moisture content is higher and lumber moisture content requirements lower for hardwoods (8% mc) than softwoods (19% mc), making drying times longer (Mackay 1980). Although shrinkage of birch wood is high, the wood is fairly easy to dry (Hyvarinen 1968; Mackay 1980). The ratio of tangential to radial shrinkage, however, is high, making birch more susceptible to cupping and diamonding. It is also not very water resistant. Water absorption after 24-hr immersion at 70°F was almost 60%, compared to only 48–52% for balsam fir, spruce, larch and poplar (Baldwin and Yan 1968).

Wood of birch is much smoother than that of poplar, aspen, pine and spruce. Planing, shaping and turning properties are fair. Nailing can cause splitting, but once the wood is nailed without splitting, the nail-holding ability is high (Hyvarinen 1968).

Tension wood, the reaction xylem in hardwoods, is formed extensively in birch. Its presence is associated with leaning stems, particularly if the angle is greater than 4°. The gelatinous fibres that characterize tension wood are usually located on the upper side of leaning stems, particularly at lower levels in the bole. Severe tension is characterized by a high proportion of gelatinous fibres and reduced vessel volume. Tension wood has a higher longitudinal shrinkage than normal wood, which leads to bowing, crooking and more severe checking of lumber and buckling of veneer (Kennedy 1968).

The chemical content of birch wood is similar to that of other hardwoods (Kennedy 1968). The holocellulose content is high (77%) and lignin content (19%) correspondingly low (Hyvarinen 1968).

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[6] Blower, D. 1982. Key winter forage plants for B.C. ungulates. Terr. Studies Branch, B.C. Min. Environ., Victoria, B.C. Unpubl. mimeo.

1.11 Wood Uses

Paper birch is typically used for dimension lumber, veneer, pulp and fuel. Other uses are for furniture, turning stock, toys and decorative molding and panelling.

Dimension Lumber

The major use of hardwoods in British Columbia has been to make factory lumber (Manning 1975). The lumber is used mainly for cross ties, crates, pallets and paneling.

In Alberta, sawlogs must be straight, free of cull and 19+ cm diameter. With careful bucking and sawing of cull-free logs, however, it may be possible to produce lumber from trees of smaller diameter (10 cm). Recovery of clear lumber from average grade birch lumber is only about 25% (Neilson 1980; Jasper Millworks and Woodland Resource Services 1987).

Veneer

The best-quality, large-sized birch trees are cut into veneer logs. Veneer grade logs must be 25 cm in diameter and 200 cm in length. Standard veneer is used to make plywood, furniture, paneling and floors. Hyvarinen (1968) reports that other uses in the U.S. include specialty products such as match boxes, cheese-boxes, ice-cream sticks, picnic spoons, plant markers, swab slats, tongue depressors and toothpicks.

Pulp

About half of the kraft pulp produced worldwide is made from hardwoods (Barnes 1980). In the southern interior of British Columbia, the greatest potential commercial use of paper birch may be for pulp. Birch can be pulped by every known commercial process, including kraft (sulphate), soda, acid sulphite, bisulphite, neutral sulphite, stone groundwood, refiner mechanical, thermomechanical, and modifications of all of these. Birch pulp has superior properties to any other hardwood species except eucalyptus (Hatton 1980). Kraft pulp has the best overall strength properties and reduces readily with high yield. It produces paper that is dense, soft, smooth and non-porous. Kraft Scandinavian birch pulp competes with sulphite coniferous pulp in strength and gives paper bulk, opacity, compressibility, smoothness and absorption power when it is blended with coniferous pulps (Hyvarinen 1968; Hatton 1980). Various types of paper can be made from the pulp, including newsprint, book papers, fine papers, corrugating papers, coarse wrapping paper, toweling and toilet tissue (Clayton 1968; Hyvarinen 1968; Barnes 1980).

Fibres of paper birch are shorter and hence the pulps are weaker than that of softwoods. Because of this fibre length, birch's tear factor, burst factor, breaking length, viscosity and folding strength are lower than for softwoods. Consequently, when paper birch is used for pulp, it is typically mixed with softwood species to make up for the short fibre content (Clayton 1968; Barnes 1980). A blend of interior softwood (70%) and hardwood (30%) pulp in Prince George has strength properties that rival those of pure softwood pulp (Barnes 1980). Barnes (1980) suggests that hardwood pulp should be marketed as a pure pulp, so that the paper maker can have direct control over the amount of hardwood pulp in any given grade of paper.

Decay and discoloration reduce the usefulness of birch as a pulp source. Paper birch lasts as well in storage as aspen or balsam fir, but not as well as spruce. It must be pulped within a year to avoid deterioration.

Composite Board

Birch is not preferred for composite board products because of its high density (Baldwin and Yan 1968). Some amounts of birch, however, can be used in mixture with low density species such as poplar (Carroll 1980).

Fuel

Firewood is an important use of small-sized birch in the southern Interior. Dry birch wood ignites readily and, because of the high specific gravity, has high heat value. Ground and compacted birch residue may also be an economical source of fuel (Blanchard and Girouard 1987).

APPENDIX 2. Literature review of black cottonwood

2.1 Distribution

Black cottonwood is found throughout south and central British Columbia, west of the Rocky Mountains. It occurs in all biogeoclimatic zones except the Alpine Tundra (AT). It is particularly abundant in major river valleys and occurs only marginally at subalpine elevations.

2.2 Habitat

Black cottonwood grows in extremely varied climatic and edaphic conditions. For optimum growth, however, the species has strict requirements for moisture, nutrients, oxygen and soil pH. These requirements are usually met through a favourable combination of soil texture, soil nutrient capital, soil depth and water table depth (Roe 1958; Fyles and Bell 1986; Dickmann *et al.* 1987).

Black cottonwood grows in warm, temperate climates ranging from relatively arid to humid. It achieves its best development, however, in humid climates (Fowells 1965). It typically grows on river banks, gravel bars and other lowland sites, but also occurs on loams, clays and humic soils of upland sites. Best growth occurs at low elevations on deep alluvial soils; the poorest growth occurs on freshly deposited gravel, primarily because of differences in compaction, aeration, moisture-holding capacity and fertility (Lyons 1952; Roe 1958; Fowells 1965; Fyles and Bell 1986).

Black cottonwood is very tolerant of short-term flooding. Its performance is actually enhanced by fast-moving, oxygen-rich water. Growth is slowed in stagnant, highly sedimented or poorly oxygenated water (Maini 1968; Krajina *et al.* 1982; Dickmann *et al.* 1987; Harrington 1987; Smit 1988). Although black cottonwood seedlings survive flooding and very low soil O_2 content for prolonged periods, they experience reduced leaf, stem and root growth, chlorosis and bronzing of leaves, necrosis, leaf abscission, root dieback, and development of hypertrophied lenticels and adventitious roots (Harrington 1987; Smit 1988). In addition, nutrient ($N0_3$, P, K, Ca, Mg) concentrations are reduced in aboveground tissues (Harrington 1987). Leaf expansion is reduced and stomata close substantially in leaves that develop during flooding (Smit 1988).

Black cottonwood has little tolerance for drought and survives in dry areas only where roots reach a permanent moisture supply (Fowells 1965; Shulte *et al.* 1987; Pezeshki and Hinkley 1988). Plants growing on wet sites that have not acclimated to water stress are unable to control water loss through stomatal function during periods of drought. However, plants that experience occasional periods of drought do modify stomatal function and leaf abscission so that they are capable of maintaining leaf water potential similar to or higher than that of plants growing on wetter sites (Schulte *et al.* 1987).

Black cottonwood has high nutritional requirements, particularly for calcium, magnesium and nitrogen. The major source of nitrogen are nitrates produced in base-rich alluvial soils (Krajina *et al.* 1982). Nitrogen activity in the wetwood of the upper bole of black cottonwood trees may also make a significant contribution to the total nitrogen input of the ecosystem (Van der Kamp 1986). Growth of black cottonwood is poor on acidic mor humus forms due to the slow release of nutrients (Krajina *et al.* 1982); it is optimal at pH values of 6–7 (Smith 1957; Roe 1958).

Black cottonwood is shade intolerant (Krajina *et al.* 1982) and does not grow in forest understories. It is replaced by more shade-tolerant vegetation unless disturbances recur (e.g., flooding) which favour black cottonwood dominance. The extreme shade intolerance limits management of black cottonwood in mixtures with conifers.

Frost resistance is high (Minore 1979), although probably lower than that of balsam poplar, since black cottonwood grows in relatively warmer climates (Krajina *et al.* 1982). Black cottonwood is injured or killed by late fall frosts (Fowells 1965), and boles are cracked and heart shake forms during severe winter frosts. Since black cottonwood breaks bud and flowers early in the spring, it is frequently injured by late spring frosts (Roe 1958; FAO 1980).

Black cottonwood is easily damaged during wind and sleet storms. Wind can cause trees to uproot, snap at a certain height, or break branches (FAO 1980). The trees often reach above the protection of surrounding trees, and winds readily break off branches in the upper third of the tree (Roe 1958).

2.3 Reproduction

Black cottonwood reproduces primarily by seed and frequently by vegetative sprouting, suckering or rooting (Haeussler and Coates 1986).

This species bears seed by age 10 and produces good crops annually. In British Columbia's interior, flowering occurs between late March and mid-June, depending on locality and lateness of the season. Fruit ripening occurs within a month of flowering and prolific amounts of seed are dispersed between early May and early July (Haeussler and Coates 1986). The buoyant seed is dispersed over long distances by wind and water. Viability of fresh seed is high but of short duration (Fowells 1965). Germination occurs readily on wet, exposed mineral soil (e.g., river bars) and seedling survival is good provided there is a favourable moisture supply. Seedling roots are intolerant of drying conditions and thus germination (on the coast) is timed to coincide with the retreat of subsurface water following river flooding (Haeussler *et al.* 1990, citing McLennan, pers. comm., 1989). Seedling establishment on clearcuts is generally poor unless sites are prepared to provide a bare, moist seedbed.

Black cottonwood readily reproduces from vegetative sprouting of stumps and roots (Roe 1958). Sprouts originate primarily from suppressed or adventitious buds and secondarily from wound callus (DeBell and Alford 1972). Other forms of vegetative reproduction include root suckering, rooting of broken stem and root fragments, and rooting of abscised shoots (Roe 1958; Galloway and Worrall 1979). Stem cuttings of black cottonwood root easily and whips (unrooted cuttings) have frequently been used to establish new plantations in the Pacific Northwest (Radwan *et al.* 1987). Artificial regeneration of stem cuttings is most successful if cuttings are collected between mid-December and mid-February, artificially rooted, and planted early in the spring while soil moisture is abundant (Haeussler *et al.* 1990, citing McLennan, pers. comm., 1989). Best establishment and growth are achieved when cuttings have healthy axillary buds (as opposed to adventitious or suppressed buds) at planting. Cuttings, therefore, should not be made from the parts of stems where maximum branching has occurred or from the tips of shoots that are usually low in stored carbohydrates (Radwan *et al.* 1987).

2.4 Genetic Diversity

Black cottonwood is genetically very diverse. This diversity is observed in its morphology, phenology, reproduction, growth rate, disease resistance (Roe 1958), and flood tolerance (Smit 1988). The abundant variation may be a selective response to the extremely variable environment which black cottonwood inhabits. Seasonal fluctuations in water flow patterns change the distribution of suitable habitat in riparian and alluvial sites. Black cottonwood is adapted to survive in this spatio-temporally heterogeneous environment through several *r*-selected characteristics (i.e., early successional; short lived; large proportion of energy allocated to reproduction; population regulated by physical factors). Genetic diversity is promoted by obligate outcrossing (dioecy), wide dispersal of seed, and broken off or abscised shoots. Fitness is also enhanced by phenotypic plasticity. Mechanisms of response to unpredictable changes include indeterminate growth, sylleptic branching, heterophylly, conversion of short shoots to long shoots, and ability to regenerate roots from shoots, and vise versa (Weber *et al.* 1985).

Genetic clines exist among populations along climatic gradients. Pauley and Perry (1954) first recognized photoperiod and temperature ecotypes in the Pacific Northwest, in which the time of height growth cessation and bud formation was correlated with latitude and altitude. Stettler *et al.* (1989) recognized several traits that follow longitudinal moisture and temperature gradients, including height and diameter growth, leaf morphology, phenology, photosynthesis, stomatal conductance and susceptibility to *Melamspora occidentalis* leaf rust. The authors suggest that latitudinal differentiation is less pronounced. Weber *et al.* (1985) recognized genetic clines among black cottonwood stands which followed a geographic gradient from southwest to northeast in Oregon, Washington and southern British Columbia. Southwestern clones had smaller leaves on more numerous and more erect branches and continued to grow later in the fall. The authors suggest that the association of smaller

leaves with numerous upright branches is an adaptation to the hotter, drier, higher light intensity environments of the southwest; heat is effectively regulated by convective cooling, and photosynthetic efficiency is improved through more diffuse light distribution and deeper light penetration into the canopy.

The genetic variation in the populations of black cottonwood that were described by Weber *et al.* (1985), is manifest in large variation in clone biomass productivity both within and among populations (Heilman and Stettler 1985). Good and bad performers came from the same population despite selection of only superior parents. The 10 best and the 10 worst biomass producers came from 6 of the 10 populations sampled. However, clones from the southwest were generally more productive than those from the northeast part of the region. This geographic trend may be attributed to parallel trends in phenology and morphology that were described by Weber *et al.* (1985).

The considerable genetic diversity and high productivity of black cottonwood are desirable characteristics for developing hybrids for short-rotation coppice culture (Heilman and Stettler 1985).

2.5 Growth and Development

Root growth

Survival of the primary root of black cottonwood seedlings during the first few days depends highly on favourable climatic conditions; the root is initially very sensitive to high temperatures and drought. During the first year, the primary root extends deep into the soil. During subsequent years, adventitious roots develop near the root collar and extend laterally near the soil surface. The deep rooting of black cottonwood enables trees to tap moisture from deep soil layers that other shallow-rooted tree species cannot (Heilman 1989). Once black cottonwood has established a deep rooting system, it can outgrow all other species (Heilman and Stettler 1985; Hinkley *et al.* 1988; Pezeshski and Hinkley 1988).

Stem growth

Black cottonwood exhibits very rapid juvenile height growth, enabling it to quickly establish and maintain a dominant position in the stand (Maini 1968). For coastal sites in British Columbia, Smith (1957, 1968) and Smith and Blom (1966) report growth rates of 5 feet in height, 1 inch in dbh and 200 ft^3/acre for the first 10 years. On coastal sites in the Pacific Northwest, heights of 10 m in 4 years (Heilman and Stettler 1985) and 14 m in 7 years (Roe 1958) are not uncommon. On subhygric sites in the southern Interior, seedlings reach 6 m and sprouts 8 m in 7 years. Young trees have a narrow, conical crown with upswept branches (Lyons 1952).

At maturity, black cottonwood is the largest deciduous tree in British Columbia. On coastal sites, a height of 36 m and diameter of 80 cm can be reached in 27 years (Haeussler and Coates 1986). In the southern Interior, a site index of 30 m at age 50 is not uncommon. Maturity is normally reached in 60–70 years, but growth can be maintained for as long as 200 years. Mature trees have a long, straight bole that is free of branches for more than two-thirds of its length (Maini 1968). The crowns tend to be large, however, with heavy branching (FAO 1980).

Poplars generally require more intensive care than other forest tree species. Badly forked and branched trees (e.g., damaged by frost, insects, disease, vertebrates) should be cut back to just below the damaged part (FAO 1980). Control of competing vegetation is essential, particularly immediately after planting. Vegetation control begins with site preparation, and should be complete for the first year after planting. It is recommended for 1–4 years after that until crowns close. Intensive control can at least double growth rates and increase resistance to climatic extremes and pests (Dickmann *et al.* 1987). Pruning to a height of 10 m when the diameter of the portion to be pruned is 12 cm is necessary to increase the proportion of clear wood (Ondro 1989).

2.6 Growth and Yield

Site Index

A single site index (100 years) equation for black cottonwood and balsam poplar was developed by the B.C. Ministry of Forests based on a sample of 426 trees. The equation is:

$$\text{Site Index}_{(100)} = \text{Height} / (b_1(1-e^{b_2 * \text{Age}})^{b_3})$$

where $b_1 = 1.1318$, $b_2 = -0.0226$ and $b_3 = 1.1223$. The factor for converting $SI_{(100)}$ to $SI_{(50)}$ is 0.73019355.

In British Columbia, the site index (50 years) on a good site ranges from 24 to 31 m, on a medium site from 16 to 24 m, on a poor site from 9 to 16 m, and on a low site from 4 to 9 m. The site index curves indicate substantial height growth between 50 and 100 years on all site classes. On a good site, site index (100 years) ranges from 34 to 42 m, on a medium site from 21 to 34 m, on a poor site from 12 to 21 m, and on a low site from 6 to 12 m (B.C. Ministry of Forests 1986).

Yield

The volume equation developed by the B.C. Ministry of Forests (1976) for black cottonwood individuals growing in the southern Interior is:

$$\log(\text{volume}) = -4.648431 + 1.735180 \log(\text{diameter}) + 1.345010 \log(\text{height}) \quad \text{S.E.} = \pm 10.6\%, \; n = 347$$

Growth and yield characteristics of black cottonwood in the Fraser River valley near Quesnel and in the Skeena River valley are described by Roe (1958). On the Fraser River valley site, culmination of periodic increment occurred after 200 years. In the Skeena River valley site, however, culmination of mean annual increment occurred between 50 and 60 years of age. The yield of black cottonwood stands in British Columbia exceeds those of aspen (Jarvis 1968) and paper birch (see Section 6).

Gross volumes of black cottonwood compare favourably with most coniferous stands. Decay, however, seriously limits merchantable volume as trees grow older. Decay in black cottonwood that shows no external signs of defect ranges up to 35%, and in those with defect, up to 45% (Jarvis 1968). As a result of the high incidence of decay, pathological rather than yield rotations must be used. The pathological rotation of black cottonwood in the southern Interior appears to occur between 60 and 70 years (see Section 6).

Stocking

In central Europe, a stocking of 400–500 stems per hectare (4 x 5 or 5 x 5 m spacing) is used to create pure, fully stocked poplar stands (FAO 1980). In British Columbia, Smith (1968) recommends planting black cottonwood at spacings of 6 x 6 m or 4.5 x 9 m to achieve a high growth rate per tree (1–2 m height per year) at the sacrifice of maximum yield per hectare. Planting only 240–270 stems per hectare would reduce establishment and spacing costs. Smith (1968) suggests that mortality among the planted trees would be low.

Short rotation culture involves planting cottonwood at spacings that are considerably closer than for conventional planting. The yield advantage, however, is limited to within the first few years of planting. Consequently, spacing is determined primarily by the expected cutting cycle and desired tree size. The minimum recommended spacing for 1- to 3-year harvests is 2 x 4 or 4 x 4 feet; for 4-year harvests, 5 x 5 feet; for 6-year harvests, 6 x 7 feet; and for 10-year harvests, 11 x 11 feet. Square spacing is not necessary since cottonwoods have the capacity to fit their crowns to the available growing space (Heilman 1989).

Thinning of poplar results in a favourable diameter growth response, particularly if stands are thinned when young. Diameter growth increases rapidly and in direct relation to thinning intensity. Although all trees respond, the large trees grow faster than the smaller ones (Jarvis 1968). Thinning studies have shown that volume production of poplar can be increased by 25% with light to moderate thinning at 5-year intervals (Steneker and Jarvis 1966). The fastest growth rates per area are achieved in 10-, 20-, 30-, 40- and 50-year-old stands by maintaining about 30, 50, 65, 85 and 100 ft^2/acre basal area, respectively. At such stocking levels, however, the maximum diameter of individual trees is not reached. Consequently, if the objective of thinning is to produce lumber or veneer, stands should be maintained at basal area levels below those for maximum total volume production (Jarvis 1968).

2.7 Succession

Black cottonwood is an early successional species. Its abundant wind-blown seed quickly germinates on recently disturbed (e.g., flooded) sites. The seedlings grow rapidly and swiftly become dominant (Walker and Chapin 1986).

Succession advances toward a black cottonwood dominated community on stable gravel river bars in British Columbia. Fyles and Bell (1986) observed in the western Rocky Mountains that the black cottonwood community develops from a Dryas Dry Gravel and Epilobium Shallow Sand community type. These community types ameliorate dry, infertile conditions by (1) adding organic matter and nitrogen to the soil, and (2) reducing water velocity and acting as a filter for silt deposition, thus increasing moisture-holding capacity. With improved fertility and moisture conditions, black cottonwood invades.

2.8 Characteristics of Mixed Black Cottonwood and Red Alder Stands.

Black cottonwood and red alder have been experimentally planted in mixture in the Pacific Northwest for short rotation intensive culture. Both species have rapid juvenile growth and high productivity, and can be coppiced in short rotation. The mixtures benefit from nitrogen addition to the soil through fixation by red alder, and also from more pest and pathogen resistance than monocultures (Harrington and DeBell 1984; Heilman and Stettler 1985; Pezeshki and Oliver 1985).

Growth patterns of 1-year-old black cottonwood cuttings and red alder wildlings were compared by Pezeshki and Oliver (1985). Black cottonwood height growth occurred earlier, 88% of it by late July. Red alder growth continued longer, with 55% of its height growth occurring after late July. The early growth of black cottonwood may be advantageous in competing for available nutrients. The leaf area ratios (an indicator of photosynthetic tissue relative to non-assimilative tissues) were higher for black cottonwood than red alder, indicating a greater productivity in black cottonwood. However, aboveground production was lower for black cottonwood than for red alder (cottonwood appears to have a preformed growth pattern, whereas alder growth continues through much of the growing season), which the authors suggest was due to cottonwood's greater photosynthate allocation to root growth. Black cottonwood outgrew red alder, however, in 5 or 6 years.

Heilman and Stettler (1985) grew black cottonwood in pure stands and in a 1:1 mixture with red alder at a spacing of 1.2 x 1.2 m. The average heights after 4 years were: cottonwood in pure stands, 10.2 m; cottonwood in mixture, 11.0 m; and alder in mixture, 8.4 m. The authors suggest that the increased height of cottonwood in mixture with alder resulted from nitrogen supplied to the soil by alder. After 4 years, aboveground biomass was 15.9 Mg/ha per year in mixture and 16.7 Mg/ha per year in pure black cottonwood stands. In contrast, after 2 years, yield was higher from the mixed planting; the change in relative productivity in the third and fourth years resulted from the declining growth rate of alder. Nitrogenase activity of red alder declined in the fourth season (5.5 vs. 18.2 µmoles/gm per hour), probably due to competition for light with over-topping black cottonwood. Soil nitrogen capital had no effect on activity.

The weight and nutrient content of 2-year-old coppices of black cottonwood and red alder grown in pure and mixed cultures were compared by Radwan and DeBell (1988). Mixed cultures resulted in yields that were higher for black cottonwood and lower for red alder when compared with monocultures. Nutrient content varied by the type of plant tissue (terminal twigs vs. leafless shoots), cultural treatment (pure vs. mixed) and species. Some of the differences may have been associated with nitrogen fixation by alder.

Flood tolerance between red alder and black cottonwood were compared by Harrington (1987). Following a 20-day flooding and 20-day recovery period, red alder seedlings increased growth rapidly when drained, while black cottonwood growth and nutrient content remained reduced. Harrington (1987) concluded that red alder was more flood tolerant, which is consistent with the ecological distribution of the two species: that is, red alder is more common than black cottonwood on poorly drained sites.

Water relations in response to field drought were compared between black cottonwood and red alder by Pezeshki and Hinkley (1988). After 3 years, stomatal conductance was greater under drought in black cottonwood than red alder. As drought severity increased, red alder's stomata closed while black cottonwood's

remained open. The differences in stomatal conductance and closure were attributed to greater root development in black cottonwood, which resulted in better use of soil moisture. In addition, black cottonwood maintained a lower osmotic potential at saturation and at the turgor loss point, indicating a greater capacity for water uptake and turgor maintenance under drought conditions. Red alder responded to drought by shedding its leaves. Premature shedding is a drought-avoidance mechanism that prevents damage resulting from water stress. The reduction in transpiring leaf area, however, could reduce productivity. Pezeshki and Hinckley (1988) concluded that a long drought period during the growing season may reduce growth of red alder far more than of black cottonwood.

The effects of irrigation and pulp mill sludge (as a fertilizer) on the growth and yield of four successive 2-year coppices of black cottonwood and red alder were examined by Harrington and DeBell (1984). Yields were generally much higher for black cottonwood (13.8 tons/ha per year) than red alder (7.1 tons/ha per year). Sludge application increased growth and yield of black cottonwood and decreased that of red alder. Irrigation increased yield of both species. Both species sprouted after all four harvests, but mortality of coppices increased and yield decreased by the fourth year, particularly for red alder.

Black cottonwood has been experimentally planted in mixture with beech in Germany, where natural regeneration of beech has failed. Black cottonwood serves to fill gaps and maintain a high proportion of deciduous trees. Similar experiments have been conducted where black cottonwood has been mixed with spruce and Douglas-fir. Cottonwood is planted at 3-m intervals along lines that are 15 m apart, with conifers planted at 2 x 2 m or 3 x 3 m between the lines. All species would be harvested at 80 years (FAO 1980).

2.9 Influence of Black Cottonwood on Ecosystem Productivity

Many studies indicate that (1) conifer monocultures lead to acidification, podzolization and degradation of forest soils; and (2) deciduous trees have a favourable effect on soil development and productivity (Frivold 1985; Richardson *et al.* 1985). Under conifer (*Picea* sp.) shelterbelts, Richardson *et al.* (1985) observed a more acid ph (half a unit) and a redder hue than under deciduous (*Populus* spp.) shelterbelts. Twelve years following planting of poplar hybrids on soddy, podzolic soils, Yakushenko (1985) found that the soils had better structure with a higher humus content, were less acid, and had more exchangeable bases and available forms of K and P. The soil-improving effects of the poplars was attributed to the intensive biological cycling of nutrients.

2.10 Pests

Insects

Several insect species attack black cottonwood. Defoliators are by far the largest group of attacking insects. The amount of damage depends on the severity of defoliation, the time of year when defoliation occurs, and the frequency of successive defoliations (Davidson and Prentice 1968).

The main order of insects that defoliate black cottonwood is Lepidoptera (moths and butterflies), of which only the larvae cause damage (Davidson and Prentice 1968; FAO 1980). The satin moth (*Stilpnotia salicis*) and the cottonwood sawfly (*Pteronidea* sp.) are the most important defoliators. Repeated defoliation by the satin moth for 4 consecutive years can cause considerable branch and limited tree mortality (Roe 1958; Davidson and Prentice 1968). Oystershell scale (*Lepidosophes ulmi*) kills twigs, branches and sometimes the entire tree (Roe 1958). Other poplar-defoliating Lepidoptera include the forest tent caterpillar (*Malacosoma disstria*), large aspen tortrix (*Choristoneura conflictana*), and bruce spanworm (*Operophtera bruceata*). The preferred host, however, is trembling aspen (Davidson and Prentice 1968).

The larvae of a number of Coleoptera bore in the roots, stems and branches of living black cottonwood. The most important are the poplar borer (*Saperda calcarata*), poplar-and-willow borer (*Cryptorhynchus*), and bronze poplar borer (*Agrilus liragus*). The poplar borer and the poplar-and-willow borer attack sparingly over the stem, boring individual galleries under the bark and into the wood. The poplar-and-willow borer prefers the thin, smooth bark of young trees; planted trees are particularly susceptible. The bronze poplar borer attacks in great numbers over a considerable portion of the tree and the larvae mine under the bark. It weakens trees by destroying the translocation tissues, making them more susceptible to subsequent borer attacks and *Hypoxylon* infections. A small cambium miner (*Lespeyresia populana*) breeds in the bark (Roe 1958).

Diseases

Black cottonwood is subject to several diseases. Decay of heartwood by many fungi is the most important cause of fibre loss in living trees. Of the many fungal species, however, significant mortality is caused by only two (*Polyporus delectans* and *Phiilota destruens*) (Roe 1958; Davidson and Prentice 1968). Many of the heartwood decay pathogens enter trees by branchwood infections and establish over a number of years; this suggests that early branch prunings might substantially reduce decay at maturity (Jarvis 1968). As well, the root disease, *Armillaria*, can spread between the bark and wood under favourable circumstances (FAO 1980).

Black cottonwood is also attacked by canker-causing fungi. The cankers gradually enlarge until they girdle and kill the main stem, or the infected part weakens and breaks off (Davidson and Prentice 1968). The cytospora canker (*Valsa sorlida*) is prevalent among young, stressed trees, such as those injured by fire or those growing on poor sites. Septoria canker (*Septoria musiva*) is particularly virulent, weakening the tree's resistance to secondary infections. Other fungal cankers of poplars include *Cytospora chrysosperma*, *Dothichiza populea*, *Fusarium solani*, and *Phomopsis macrospora* (FAO 1980; Dickmann *et al.* 1987).

Black cottonwood of all ages is attacked by a number of fungi which form galls. The fungus penetrates the intact cuticle and epidermis and stimulates hypertrophy of the xylem, phloem and cambium (Davidson and Prentice 1968; FAO 1980). The poplar bud-gall mite (*Aceria parapopuli*) feeds on tissue of these galls. Many fungi also attack the leaves of black cottonwood and can cause reduced growth of severely affected trees. The most common foliage diseases include leaf rusts (*Melampsora occidentalis*) (Heilman *et al.* 1989), ink spot (*Ciborinia whetzelii*) (Davidson and Prentice 1968), and shepherds crook (*Venturia populina*) (FAO 1980; Heilman *et al.* 1989; Stettler *et al.* 1989).

Vertebrates

Woodpeckers damage black cottonwood wood by piercing the bark and feeding on sap. They are useful, however, in that they prey on wood boring insects. Beavers and voles feed on cambium and beavers also use black cottonwood for dam construction. Hares damage young plants by gnawing the bark just above ground level. Squirrels and doormice gnaw the bark off branches, which dry and break in the wind. Pocket gophers, muskrats and water-rats feed on roots. Among the ungulates, deer and cattle can cause considerable damage in young plantations. Deer strip and rub bark and cattle eat leaves (Heilman *et al.* 1989; FAO 1980).

2.11 Wood Quality and Properties

The wood of black cottonwood is light, soft, and low in strength. The heartwood is grayish brown and the sapwood nearly white (Hosie 1969). At maturity, black cottonwood has heavy, deeply furrowed bark, which may discourage its use (Ondro 1989).

The *Populus* genus generally lacks inter-species variation in wood properties (Fitzpatrick and Stewart 1968; Gol'traf 1982). Cottonwoods and balsam poplar tend to have a coarser texture, however, than aspens (Kennedy 1968).

Poplar wood is generally low density and diffuse porous, with little difference in the number and size of vessels in the early and late wood (FAO 1980). Fast-grown cottonwood tends to exhibit a semi-ring porous structure. Vessels occupy approximately 20–33% and fibres 56–79% of the cross section. The rays are generally uniseriate and the parenchyma count is low (Kennedy 1968; FAO 1980). As in most hardwoods, the fibre tracheids are short (Hyvarinen 1968). Fibre length increases from earlywood to latewood (10–20%) and with increasing age from the pith. Fibre length also may increase with rate of growth (Kennedy 1968).

Black cottonwood is considerably less dense than other poplars (specific gravity of wet wood is 0.30–0.32 g/cm^3 for black cottonwood and 0.35–0.39 g/cm^3 for trembling aspen). Specific gravity is highly variable due to environmental and genetic effects, and density is negatively affected by fast growth in managed stands. Wider ring widths can result in less solid wood, as well as decreased hardness, compression and bending strength (Kennedy 1968).

Because of its low specific gravity, black cottonwood (and other poplar) wood is weak. Its compression strength, specific bending strength and crushing resistance are generally inferior to other species. The modulus of elasticity, however, is similar to that of other species with the same specific gravity (Kennedy 1968). Flexural strength is similar to that of paper birch (5700 psi) (Baldwin and Yan 1968).

The average green moisture content of black cottonwood is very high (175%) compared with paper birch (72%) and aspen (90%). The moisture content is higher and lumber moisture content requirements are lower for hardwoods (8% mc) than for softwoods (19% mc), making drying times longer (Mackay 1980). The high moisture content of cottonwood results in high shrinkage. The ratio of tangential to radial shrinkage is high, making black cottonwood more susceptible to cupping and diamonding (Kennedy 1968). Other problems associated with high moisture content include the high cost of extraction, transport, handling and storage, susceptibility to fungal attack, and difficulty in sawing and peeling (FAO 1980).

Black cottonwood is relatively water resistant. Water absorption after 24-hr immersion at 70°F was only 50%, compared to 58% for paper birch and 48–52% for balsam fir, spruce and larch (Baldwin and Yan 1968).

Black cottonwood cuts roughly because of its low specific gravity, high moisture content and porous structure. The roughness or wooliness can be further accentuated by the presence of tension wood.

Tension wood is found extensively in black cottonwood. Its presence is associated with leaning stems, particularly if the angle is greater than 4°. The gelatinous fibres that characterize tension wood are usually located on the upper side of leaning stems, particularly at lower levels in the bole. Severe tension is characterized by a high proportion of gelatinous fibres, reduced vessel volume and higher specific gravity. Tension wood has a higher longitudinal shrinkage than normal wood, which leads to bowing, crooking and more severe checking of lumber and buckling of veneer (Kennedy 1968).

The carbohydrate content of black cottonwood is remarkably high (60–70%) and lignin content correspondingly low (15%). The ash content is 0.5–1.0% (FAO 1980). The higher cellulose content is not necessarily advantageous, because lower hemicellulose content may result in weaker pulp (Kennedy 1968).

2.12 Wood Uses

Black cottonwood historically has been used primarily for dimension lumber, veneer, particle board, pulp and fuel. Other uses have been for packaging, crates, poles, posts, cattle feed, and shavings for cattle bedding. In more recent years, black cottonwood and its hybrids have been cultivated for energy. Plantations also have been used as waste disposal sites.

Dimension Lumber

The production of poplar lumber has gradually increased in Canada since 1975. Three-quarters of production of poplar lumber comes from Quebec and Ontario and only small quantities from British Columbia, Alberta and Manitoba. Most dimension lumber is used for low-quality pallets, panelling, framework, roofing, doors, windows and furniture products. The main reasons for the limited use of dimension lumber are la[illegible] of a consistent supply, range of sizes and grades, and the relatively high prices (Ondro 1989).

Manufacture of dimension lumber from black cottonwood has been limited by several technical problems. The lumber tends to twist as a result of large quantities of tension wood in almost every tree. Green lumber has a very high moisture content (average green moisture content is 175%) and thus must be air dried and then kiln dried to avoid warping and twisting (Mackay 1968; Ondro 1989). The amount of ring shake is substantial, which makes sawing difficult. The incidence of decay is very high, so lumber recovery is very low (less than 25% for veneer bolts) (Harris 1968; Ondro 1989). Finally, the wood is prone to fungal attack and can deteriorate rapidly (FAO 1980). Under these circumstances, only mill operators close to high-quality stands and markets can compete with softwood lumber in a limited range of products (Ondro 1989).

The incidence of decay limits the production of dimension lumber for two reasons. First, black cottonwood matures and starts to decay at an early age. Because unmanaged cottonwood stands are under-used, they are becoming increasingly decadent over time. Second, the poplar-based industry has depended heavily on large-

dimension logs. Large sound logs are becoming increasingly difficult to get. There is a need to shift the emphasis toward the use of small-dimension logs that can be produced in less than 50 years (Thomas 1968).

Limited sawmill tests in the Pacific Northwest show that hybrid poplar is superior to black cottonwood for lumber. Advantages include easier debarking because of less fibrous bark, lighter coloured heartwood, fewer epicormic branches or other defects affecting lumber quality, and straighter boles with less tension wood (Heilman *et al.* 1989).

Veneer and Plywood

Black cottonwood has been used to a limited extent as core stock for the manufacture of plywood, sheathing and surfacing for other species, primarily Douglas-fir (Heilman 1989). Its low density and excellent gluing characteristics make black cottonwood veneer an ideal core and crossband material for panels faced with softwoods or more valuable hardwoods (Feihl and Godin 1968). In Europe, the clear, white colour of poplar wood is desirable in the manufacture of plywood (FAO 1980). In British Columbia, unfortunately, the Council of Forest Industries (COFI) prohibits the use of poplar in Canadian softwood plywood, precluding the establishment of any sizable market for poplar veneer in western Canada (Ondro 1989).

Black cottonwood veneer is desirable for shipping containers because of its light weight, toughness, resistance to splitting in nailing, smoothness, and lack of odour. It is also superior to many species for painting because of its enamel and paint-holding properties, light colour and lack of grain.

Pulp

Chips of poplar wood have proven to be excellent for the manufacture of pulp and paper. Several British Columbia and Pacific Northwest pulp mills accept black cottonwood as part of their wood supply (Fitzpatrick and Stewart 1968; Heilman 1989). Poplar is suitable for pulping by all commercial methods and is being commercially pulped by mechanical (pressurized ground wood), semi-chemical (chemi-mechanical), sulfate (kraft), sulfite and defibration processes. It is usually used in combination with softwoods, where 20–100% of the pulp mix is poplar, depending on the suitability of the mill (Fitzpatrick and Stewart 1968; Hatton 1980; Stettler *et al.* 1989). Mixed poplar pulp is used in every major class of paper and board product, including high-grade paper, towels, tissues, sanitary products, and containers (Hatton 1980; Ondro 1989).

Several special features of poplars affect the kraft and sulfite pulping processes. First, hardwoods in general have a lower lignin content than softwoods. Consequently they pulp faster and give a higher yield at a given pulp lignin content than softwoods do using the kraft process. Second, poplars have a lower basic density than all other Canadian hardwoods. As a result, the yield of pulp is frequently lower. Third, fibre length is lower and pulp is thus weaker than that of softwoods. Therefore, poplar pulp is blended with longer-fibred softwood pulp. Poplar kraft and sulfite pulps have high opacity and good bulk and printability. Softwood blends containing 10–40% poplar are used in book, printing, and other fine papers (Clayton 1968).

Small amounts (~1%) of poplar are included in softwood mixtures to make groundwood pulp for newsprint. As with chemical pulps, the shorter fibre length of poplar produces a weaker groundwood pulp than do softwoods. In comparison with other pulps, however, the bulk, absorption and light scattering of groundwood pulps make them suitable for a range of paper, board and tissue application (Hatton 1980). Larger amounts of poplar chips (up to 75%) are included in groundwood for the manufacture of insulating board. High percentages (up to 65%) are also used in the manufacture of toilet tissues because of the softness, bulkiness, lack of odour, and brightness of the pulp. Refiner pulps have superior strength properties to stoneground pulp and can be made from relatively cheap sawmill-residual chips (Hatton 1980). Decay occurs quickly, however, making storage of chips a problem. Decay of poplar is about 25% faster than decay of spruce-balsam, and even faster when stored with its bark attached (Clayton 1968).

Poplar is a desirable wood for the neutral sulfite semi-chemical pulping process (NSSC). Typically, NSSC pulp yields 70–85% and contains a high percentage of lignin and hemicellulose. The process is more suited to hardwoods than softwoods because of their lower lignin content. Poplar produces a brighter NSSC pulp at a lower cost than do softwoods. The pulps have low strength but possess high stiffness, making them suitable for corrugating medium and newsprint filler (Clayton 1968).

Composite Board

Poplar species are preferred for composite board products (e.g., wafer board, oriented strand board, particle board, hardboard and fibre insulation board) because of their low density, good compactability, light colour, uniformity of pulp quality, and water resistance (Baldwin and Yan 1968; Carroll 1980; Heilman 1989). Poplars are ideal because the industries do not demand large, premium logs. In addition, the trees are straight, easily limbed and easily barked (except when frozen). Debarking of logs is not necessary, however, as demonstrated in Europe (FAO 1980). One negative aspect of the use of black cottonwood is the species' high moisture content, which aggravates drying processes (Baldwin and Yan 1968).

The use of poplar in composite board in Canada is gradually increasing. As of December 1988, there were 16 waferboard and oriented strand-board mills in Canada with a combined capacity of 2412 MM ft^2/yr. The largest, Louisiana Pacific, is located in Dawson Creek, B.C., and has a capacity of 260 MM ft^2/yr (Ondro 1989).

The vast majority of Canadian particle board is made up of 100% poplar. Less poplar is used in the wet process hardboard manufacture, probably because of its limited local availability (Baldwin and Yan 1968).

Fuelwood

Black cottonwood is not regarded as a desirable fuelwood, because of its low density and high moisture content. However, the small and young material can be readily converted to fuel pellets for pellet-fired and thermostatically controlled home heaters (Heilman 1989).

Energy

Energy production is a primary use for short rotation intensive culture of poplar hybrids. One of the original research objectives of the American Department of Energy was to produce wood chips for use in electrical generation. Currently, a midwestern utility is studying the feasibility of establishing biomass plantations to feed a wood-fired electrical generation plant. The facility would burn the whole tree instead of chips. More recently, however, the emphasis has shifted away from electrical generation to production of a liquid similar to diesel oil. The liquid, to be made from wood by a thermo-chemical conversion process, would be used primarily as fuel for vehicles (Heilman 1989).

Waste Disposal Sites

Short rotation intensive culture poplars can be grown on disposal sites for municipal sludge, wastewater, nutrient pollution adjacent to agricultural areas (Stettler *et al.* 1989), and pulp mill sludge (Harrington and DeBell 1984).

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